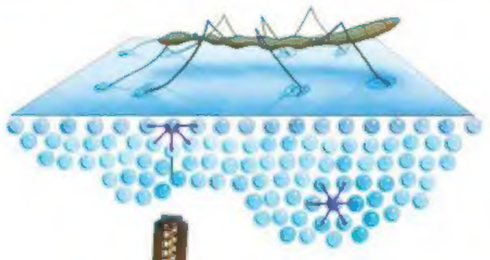
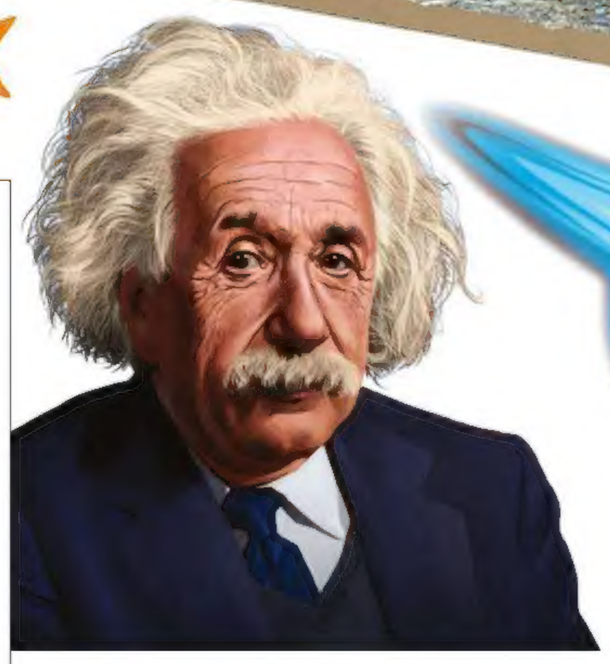
Everything you want to know about the world we live in

NEW

HOW IT WORKS ANNUAL





1000s OF AMAZING FACTS INSIDE

Digital Edition

FUTURE

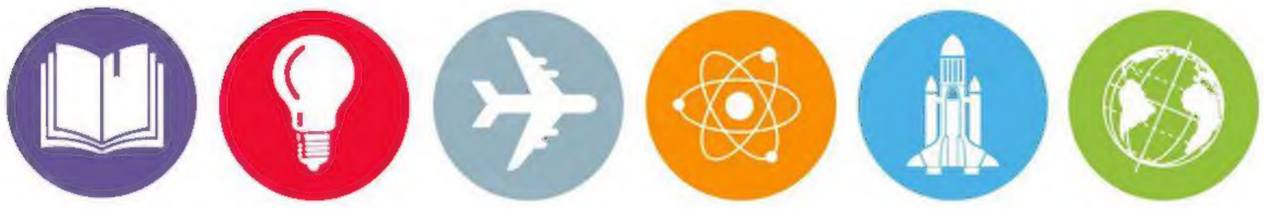
VOLUME 15

SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

WELCOME TO

HOW IT WORKS Annual

We've opened this edition of the How It Works annual with a special feature on the physics of Time, shortly followed by a tour of the most massive and ominous celestial objects in the universe - supermassive black holes. These two subjects science cannot properly explain, are mind-blowing in every way, and encapsulate the length and breadth of human understanding. That's the scope of what's gone into volume fifteen: time, space, and everything in between, including how Earth got its water, human brain transplants, incredible secret underground structures, how astronauts train for life and work in space, the must-have gadgets and electronic devices of the 1980s, the future of steam power, plus loads more. They're the choicest articles from the last 13 issues that we think you will both love the most and will feel most relevant to you right now. So kick back with a cuppa and prepare to feed your mind with over 140 pages of fascinating science and techology facts, stats and questions answered. Enjoy!



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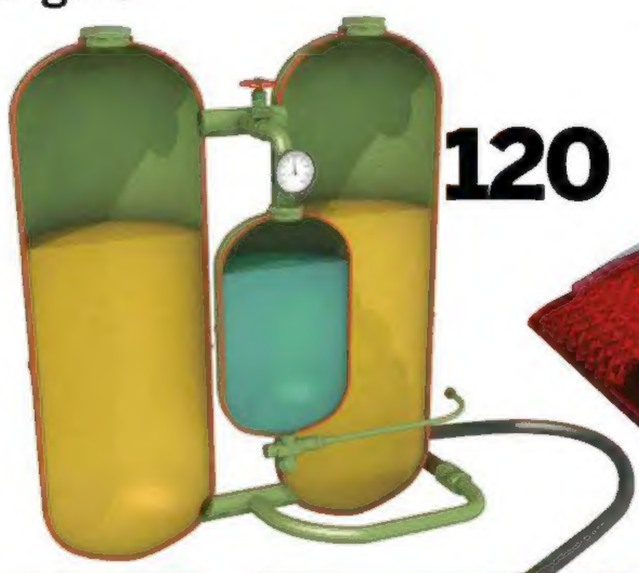

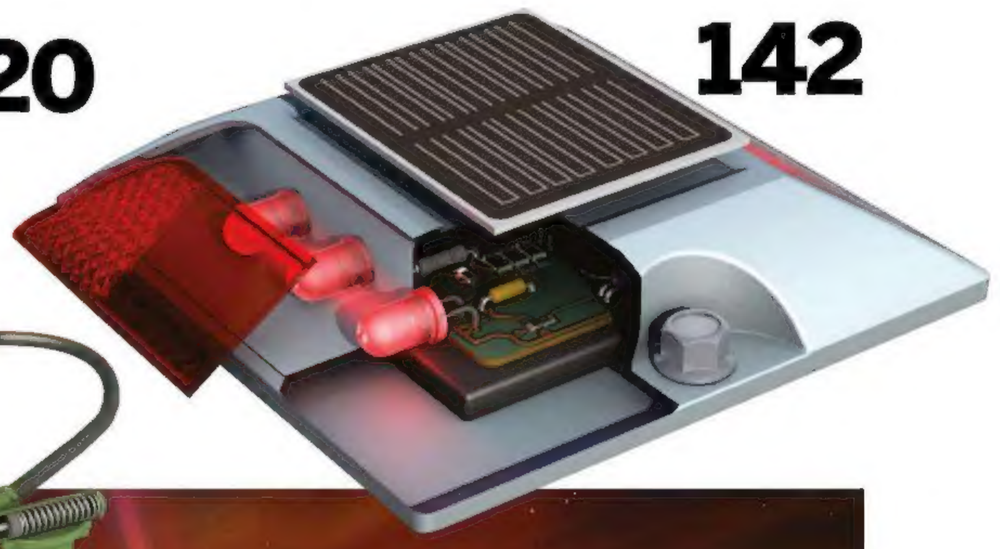

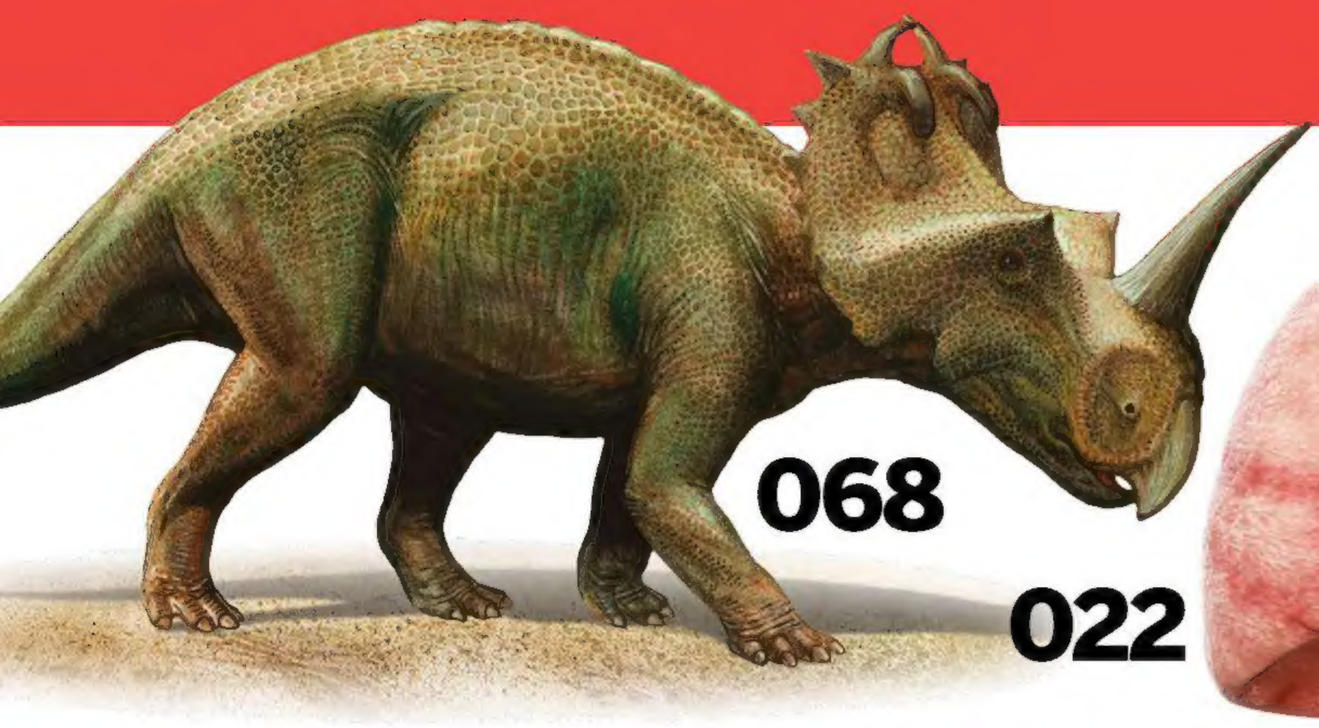

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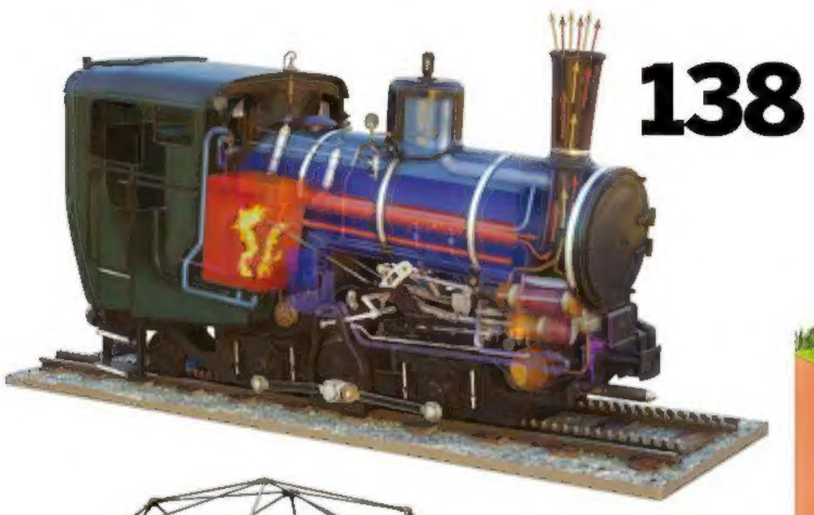

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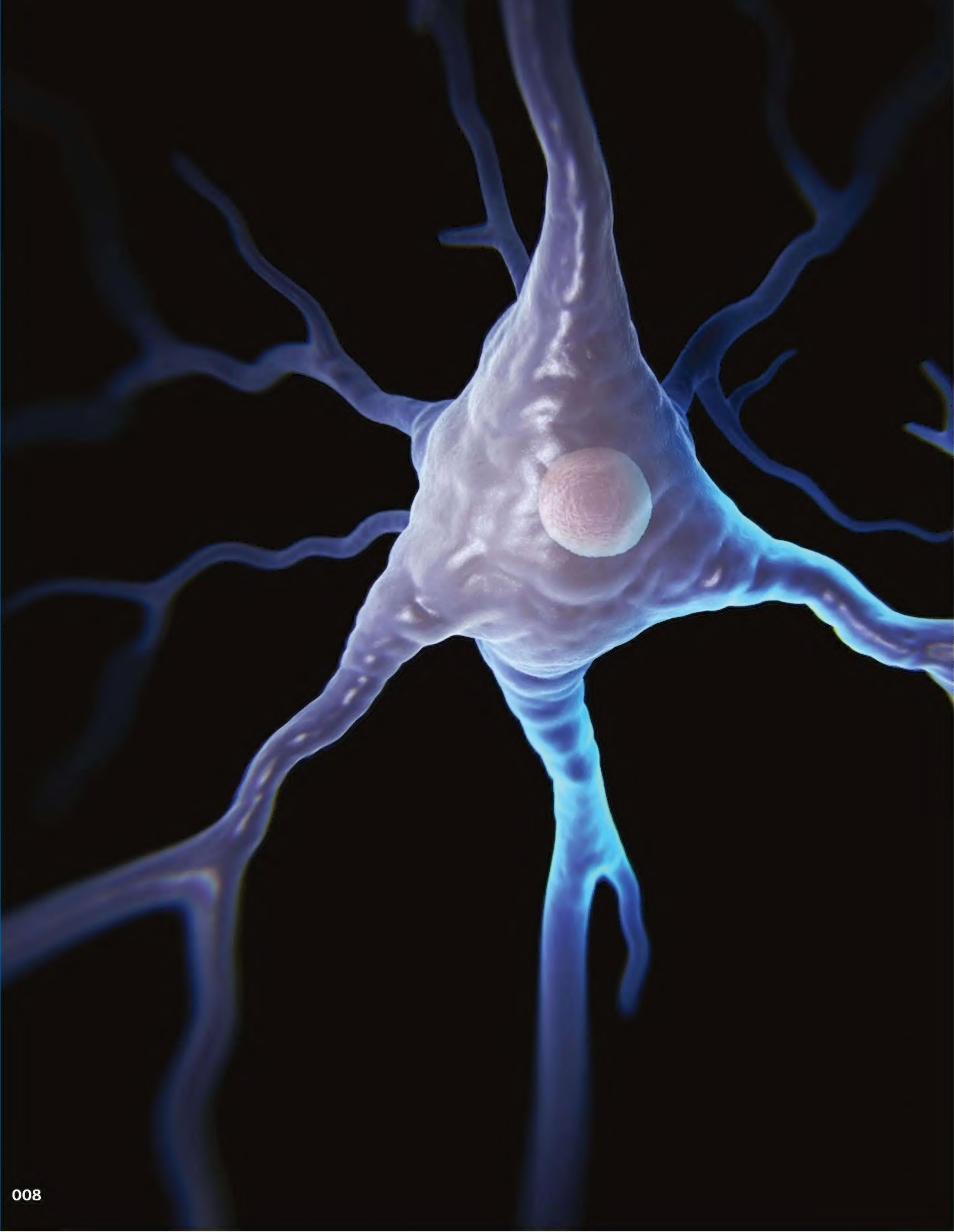


SCIENCE

TIME

What is time? A look at some of the ways we measure this unstoppable force of nature and its intimate connection with space

WORDS ANDREW MAY

DID YOU KNOW? In ancient times, an hour was a 12th the duration of daylight, varying in length with the seasons

TIME

Time is something we all take for granted, yet it can be very difficult to grasp when we think hard about it. As long ago as 400 CE, Saint Augustine remarked that he knew exactly what time was, except when he tried to explain it. Many of us might say the same thing today, and the world's philosophers are still arguing with about the exact nature of time and how we perceive it. Fortunately, there are some aspects of the subject that we're now able to pin down much more precisely, thanks to super-accurate timepieces and sophisticated mathematical theories. The next few pages are a guided tour of some of the most fascinating highlights. We'll start by looking at the way our measurement of time has evolved over the centuries, from ancient sundials and megalithic calendars like Stonehenge, through the earliest mechanical timepieces to the ubiquitous quartz-driven electronic clocks and watches of today. Then we'll take a dip into Einstein's mind-bending theory of relativity, which shows how space and time are intimately interconnected, and how different observers can see time passing at different rates. Finally, we'll come bang up to date with the latest generation of high-tech atomic clocks, some of which are so accurate that they wouldn't lose so much as a second in the entire lifetime of the universe.

The Aztec calendar seen here is a more recent relative of the ancient Mayan calendar

GOING BACK IN TIME

For prehistoric people, keeping track of the time of year was much more important than knowing the time of day. As a result, their most sophisticated attempts at timekeeping were not so much clocks as calendars. They watched the Sun and Moon changing position in the sky in order to keep track of the seasons, and several of their most striking monuments are built around solar or lunar alignments for this purpose. The summer solstice alignment of Stonehenge is the most famous of these, although Newgrange in Ireland – which is aligned with the winter solstice – is equally impressive and even older.

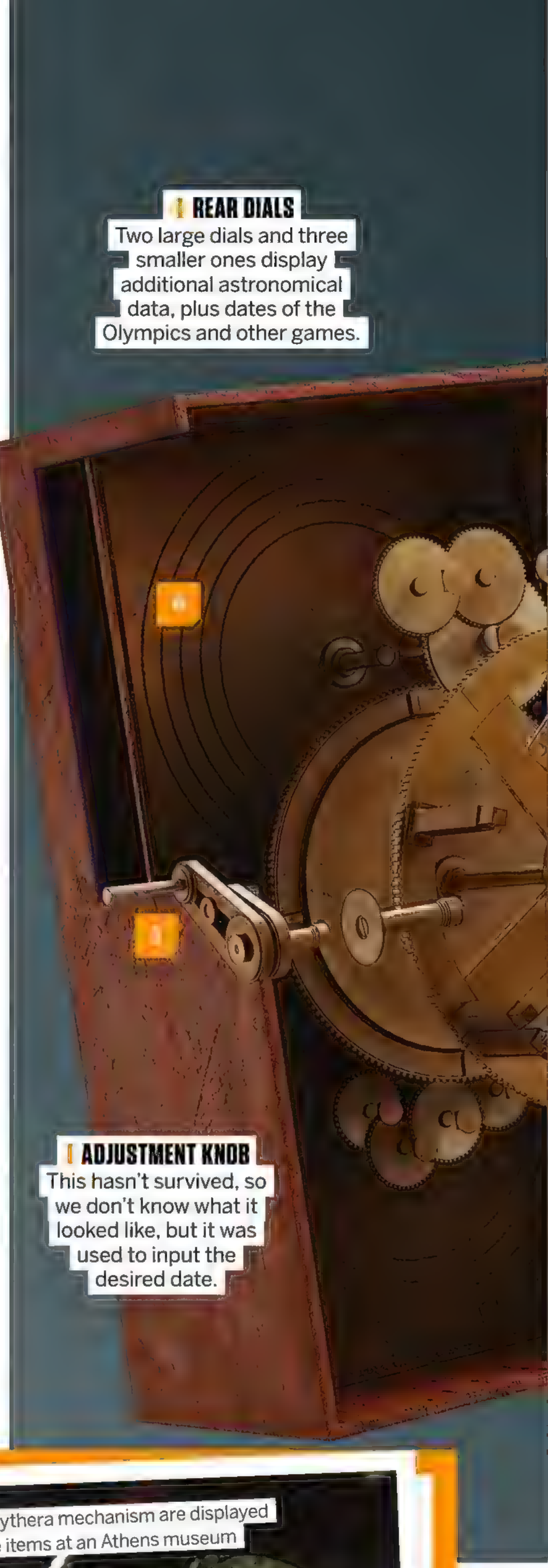
As for the time of day, the oldest and simplest method of working it out also used the Sun. This is the sundial, which does have the disadvantage that it won't work at night or on a cloudy day. A more reliable alternative, which emerged in ancient Egypt, is the water clock. This may be less familiar today than the hourglass, a somewhat later invention, but it works on the same basic principle, just using flowing water instead of sand grains.

Did You Know?

The oldest known sundial dates from 1500 BCE

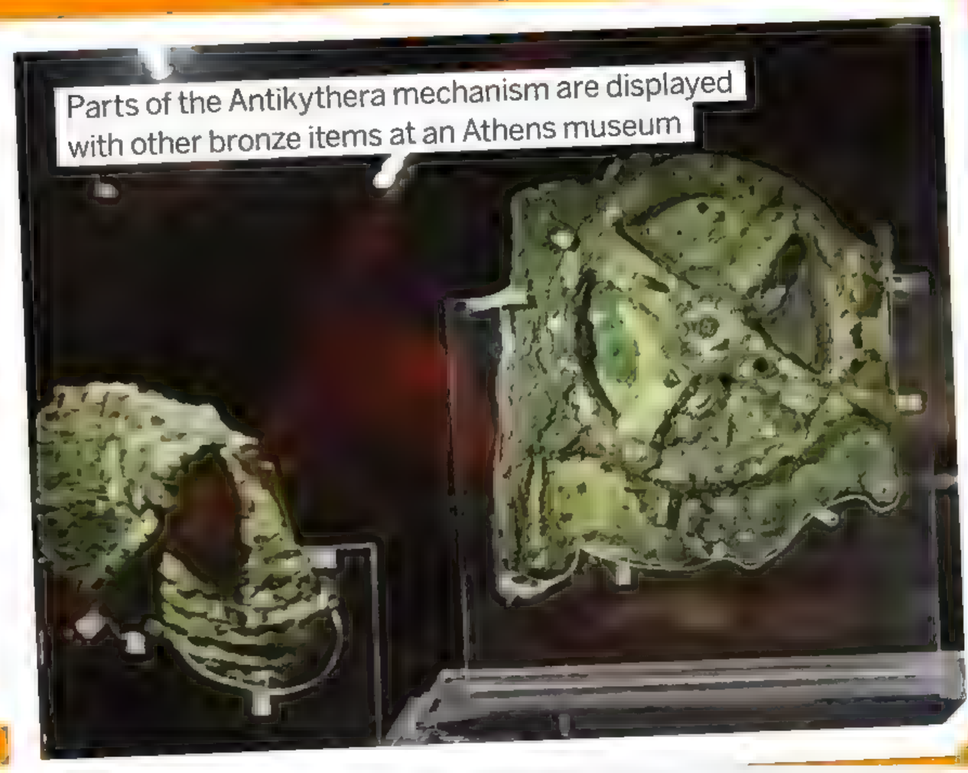
The first mechanical clocks appeared in the latter part of the 13th century. A European invention, these were based around a system of weights, levers and gears – 'clockwork' in other words. The earliest such mechanisms didn't have familiar clock faces, but simply struck a bell every hour. They were the first devices to actually bear the name 'clock', from the Latin word clocca, which means 'bell'.

Over the following centuries, timepieces were gradually refined and improved in two directions: towards greater precision and greater practicality. A major leap forward in accuracy came in the latter part of the 17th century, with the introduction of pendulum clocks. This allowed precise minutes and even seconds to be shown as well as hours. In regard to practicality, clocks gradually



ANCIENT GREEK COMPUTER

Sometimes called the world's oldest computer, the Antikythera mechanism is a complex calendrical device made some time around 100 BCE. It gets its name from the fact that it was found in a shipwreck off the Greek island of Antikythera, although it probably originated on another island, Rhodes. Made of bronze and roughly the size and shape of a shoebox, it's badly corroded but intact enough for scientists to see how it must have worked. Turning a knob on the side would set the desired date, which via a complex set of gears inside the box would operate a number of display dials on the front and rear faces. The front one showed the positions of the Sun, Moon and planets relative to the zodiac, while the rear dials showed things like solar and lunar eclipses – and possibly of more interest to some of its users, the timing of various sports tournaments.



Parts of the Antikythera mechanism are displayed with other bronze items at an Athens museum

DID YOU KNOW? A pendulum clock will run slower if raised from sea level to a mountaintop, where gravity is weaker

INSIDE THE ANTIKYTHERA MECHANISM

This sophisticated device from the ancient world was a multifunction calendar

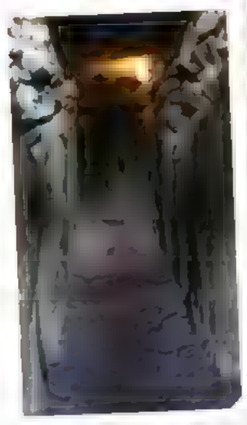
"They watched the Sun and Moon changing position in the sky"

3 GEARS
The inside of the box contains over 30 precision-engineered gears that drive the front and rear displays.

2 FRONT DIAL
This is the main output of the device, showing planetary movements and other astronomical data.

Although hourglasses are rarely used today, they have become a familiar computer icon

KEEPING TIME



3200 BCE
Prehistoric people made a kind of calendar at Newgrange, which fills with sunlight at just one moment each year.

450 BCE
The Mayan calendar of Central America was one of the most sophisticated timekeeping systems in the ancient world.

685 CE
A sundial showing the correct times for prayer was installed outside Bishopstone Church in East Sussex.

1270
The first mechanical clocks, with bells but no hands or dials, appeared in northern Italy and southern Germany.

became smaller, with pocket-sized watches making their first appearance as early as 1574, followed by the first wristwatch in 1812. Also around the early 1800s, the first mass-produced clocks hit the market, making them much more widely available than before.

Prior to the 19th century, knowing the exact time had been more a matter of curiosity than necessity. With the growth of rail travel, however, people suddenly had a much stronger motive for knowing what the time was. Trains ran to strict timetables, and you could miss your connection if you were a few minutes late. In the early days of rail travel, different parts of the country even had their own local time standards, which caused considerable chaos before national time zones – such as Greenwich Mean Time in the UK – were introduced.

Although traditional 'clockwork' clocks and watches dominated for several centuries, it's quite likely you don't have a single one in your home today. This is due to a discovery that was made early in the 20th century concerning a common mineral called quartz. If a crystal of it is incorporated into an electronic oscillator circuit, it produces a signal with a very precisely defined frequency. This discovery made it possible to construct timepieces that were at least ten times more accurate than the best traditional clocks. The first such 'quartz clock' was built in 1927, but it didn't create an immediate revolution. This was because the electronic devices of those days were bulky and unreliable, and it was several decades before a later generation of miniaturised electronics made quartz clocks and watches a viable proposition – so much so that they've become virtually ubiquitous today.

Did you know?

[illegible]

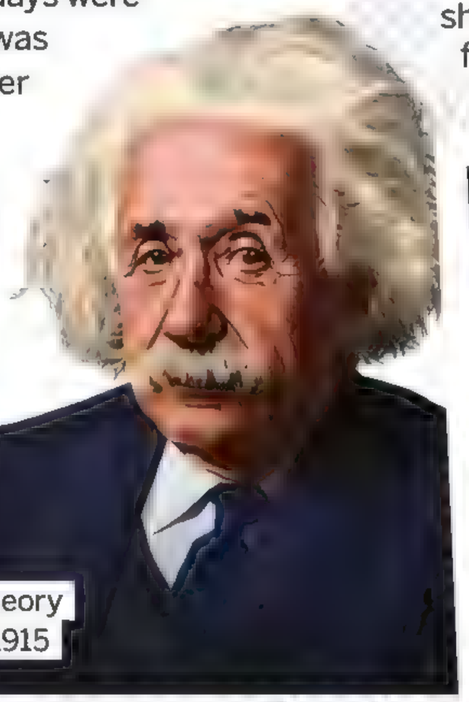
EGYPTIAN WATER CLOCK

This simple-but-effective timepiece has been around for at least 3,400 years

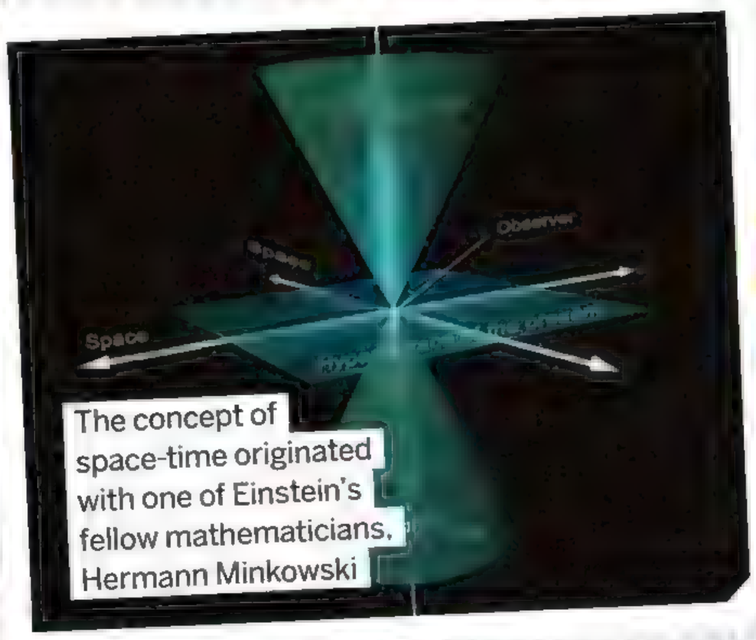
1 FILL POT WITH WATER
To start the clock, pour water into the funnel-shaped pot until it's filled to the brim.

2 LET WATER DRIP OUT
After the inflow stops, water continues dripping at a steady rate from a small hole in the bottom.

3 READ OFF TIME
As the water level drops, compare it with the graduated markings to see how much time has passed.



Albert Einstein developed his theory of relativity between 1905 and 1915



The concept of space-time originated with one of Einstein's fellow mathematicians, Hermann Minkowski

"It works on the same basic principle, using flowing water instead of sand"

1656
Dutch scientist Christiaan Huygens designed the first pendulum clock, and had it built by a local clockmaker.

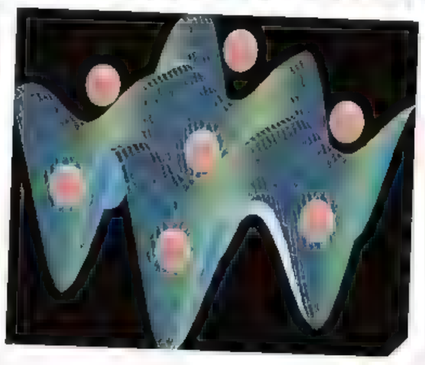
1847
Greenwich Mean Time (GMT) was adopted as the official 'railway time' throughout Britain.

1915
Einstein published the final part of his theory of relativity, which revolutionised the way physicists view time.

1967
Electronic wristwatches based on quartz-crystal oscillators were demonstrated for the first time.

1989
Physicist Norman F. Ramsey was awarded the Nobel Prize for his role in the development of atomic clocks.

2018
An optical lattice clock at America's National Institute of Standards and Technology set a new world record for precision timekeeping.



DID YOU KNOW? Tipler cylinders are a more practical hypothetical method of time travel than wormholes

THE RELATIVITY OF TIME

In everyday life, we take it for granted that time ticks away at a constant rate. This is borne out by the fact that clocks all over the world remain synchronised with each other. To physicists, however, this is only because we all share the same frame of reference. Ever since Albert Einstein formulated his theory of relativity in the early years of the 20th century, it's been known that time can be perceived differently by observers in substantially different frames of reference, for example if they are in rapid motion or a strong gravitational field.

One notion that has to be thrown out in Einstein's theory is the idea of simultaneity. An observer on Earth might perceive two astronomical events as happening simultaneously, while the pilot of a fast-moving spaceship would see them occurring at different times. Similarly, the space-travelling and Earthbound observers might obtain different answers when measuring the duration of an event at a third location. Known as time dilation, this effect occurs in two distinct situations: if the two observers are moving relative to each other, or if one of them is in a stronger gravitational field. These 'relativistic' effects aren't quite as weird as they sound, because they only relate to the way observers see time passing at some location other than their own. For the observers themselves, time always passes at its normal rate.

A highly conceptualised image of a wormhole, which in principle would allow time travel

IS TIME TRAVEL POSSIBLE?

One of the oddest consequences of relativity is that it allows the possibility of time travel. The immensely strong gravitational fields surrounding black holes can distort space-time so much that it folds back on itself. The result is a 'wormhole'. Like its fictional counterpart, a real-world wormhole acts like a shortcut between different points in space-time – and it's perfectly possible for the wormhole's exit to lie at an earlier time than its entrance. A path through space-time that loops back into the past is known as a 'closed timelike curve', and physicists have worked out several ways of creating them. Unfortunately, these all require impossible feats of engineering, so time travel remains a purely theoretical, rather than practical, possibility.

5 FACTS ABOUT TIME DILATION

1 SLOWED DOWN MUON DECAY
Super-fast muon particles are created by cosmic rays hitting the upper atmosphere, and they're so short-lived they should never reach ground level – but they do, thanks to time dilation.

2 CLOCKS ON A PLANE
Even at ordinary speeds, time dilation has measurable effects at the sub-microsecond level. This was demonstrated in 1971 when scientists took atomic clocks on round-the-world flights.

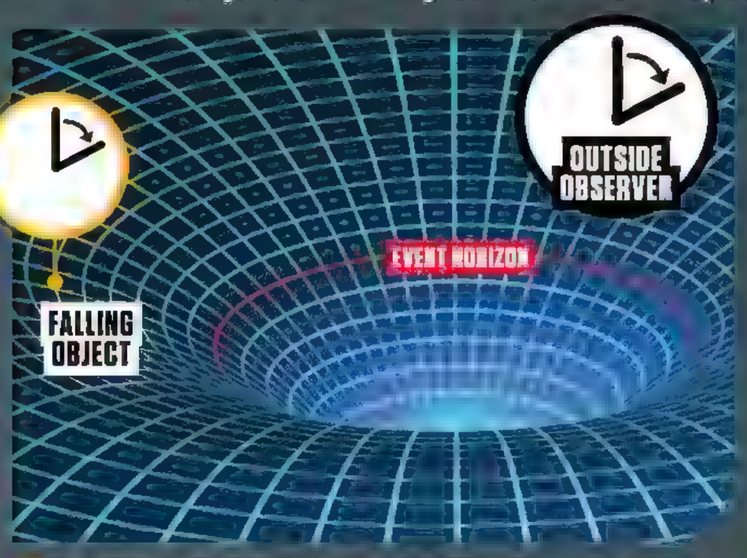
3 RELATIVITY AND GPS
To provide metre-level navigational accuracy, GPS satellites need nanosecond-accurate timing. They can only achieve this by taking the effects of relativistic time dilation into account.

4 LARGE HADRON COLLIDER
Protons whiz around the collider so rapidly that if they continued for two hours by an external clock, they would experience little more than a second of their own time.

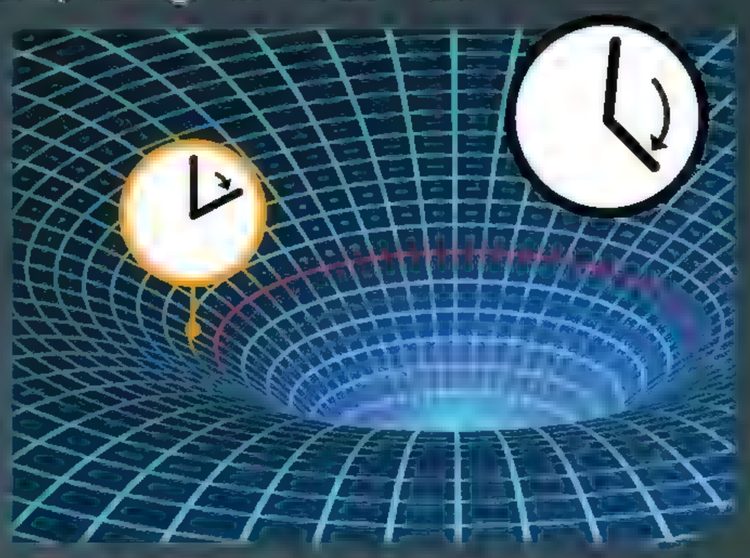
5 NASA'S TWINS
When astronaut Scott Kelly did a stint on the International Space Station, time dilation meant he aged approximately five milliseconds less than his twin brother Mark, who remained on Earth.

BLACK HOLE TIME DILATION

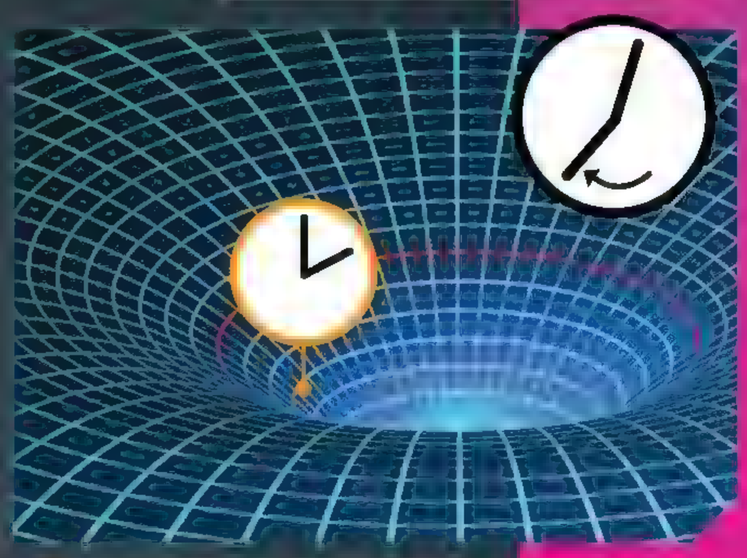
This is what you'd see if you watched a spaceship falling into a black hole



1 SPACESHIP APPROACHES A BLACK HOLE
As long as the ship is still a safe distance from the black hole's event horizon, the distortion of space-time is relatively small, and events are seen to occur at the same rate by an outside observer and by the ship's crew.



2 SPACESHIP FALLS IN TOWARDS THE EVENT HORIZON
From the perspective of the crew, nothing has changed – they're still travelling at the same speed. But an outside observer sees the ship slowing down – and if they could see inside, the ship's clock would be slowing down too.



3 SPACESHIP REACHES THE EVENT HORIZON
As far as the passage of time is concerned, the crew would see nothing special at this point. But for the external observer, the ship grinds to a halt and becomes frozen in position on the event horizon.

THE EVENT HORIZON TELESCOPE

Atomic clocks are crucial to the way this world-spanning telescope array works

TIME DELAY

VERY LONG BASELINE

CLOCK 1

CLOCK 2

1 ASTRONOMICAL OBJECT
This might be a distant galaxy or a small object in our own galaxy, such as the central black hole.

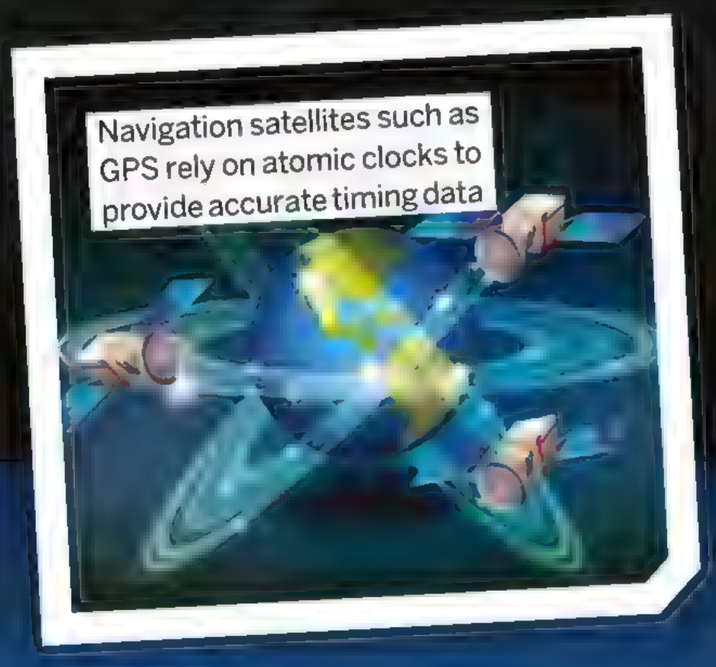
2 RADIO SIGNAL
The same signal is received by all the radio telescopes in the array.

3 INDIVIDUAL TELESCOPE DISHES
Each telescope records the time the signal arrives using an atomic clock.

4 DIFFERENT ARRIVAL TIMES
The signal will reach the telescopes at different times, separated by milliseconds.

5 TELESCOPE SEPARATION
The distance between the telescopes, or baseline, needs to be known very accurately.

6 BASELINE CALCULATION
The difference in arrival times, as recorded by the atomic clocks, provides a precise measure of the baseline.



Navigation satellites such as GPS rely on atomic clocks to provide accurate timing data

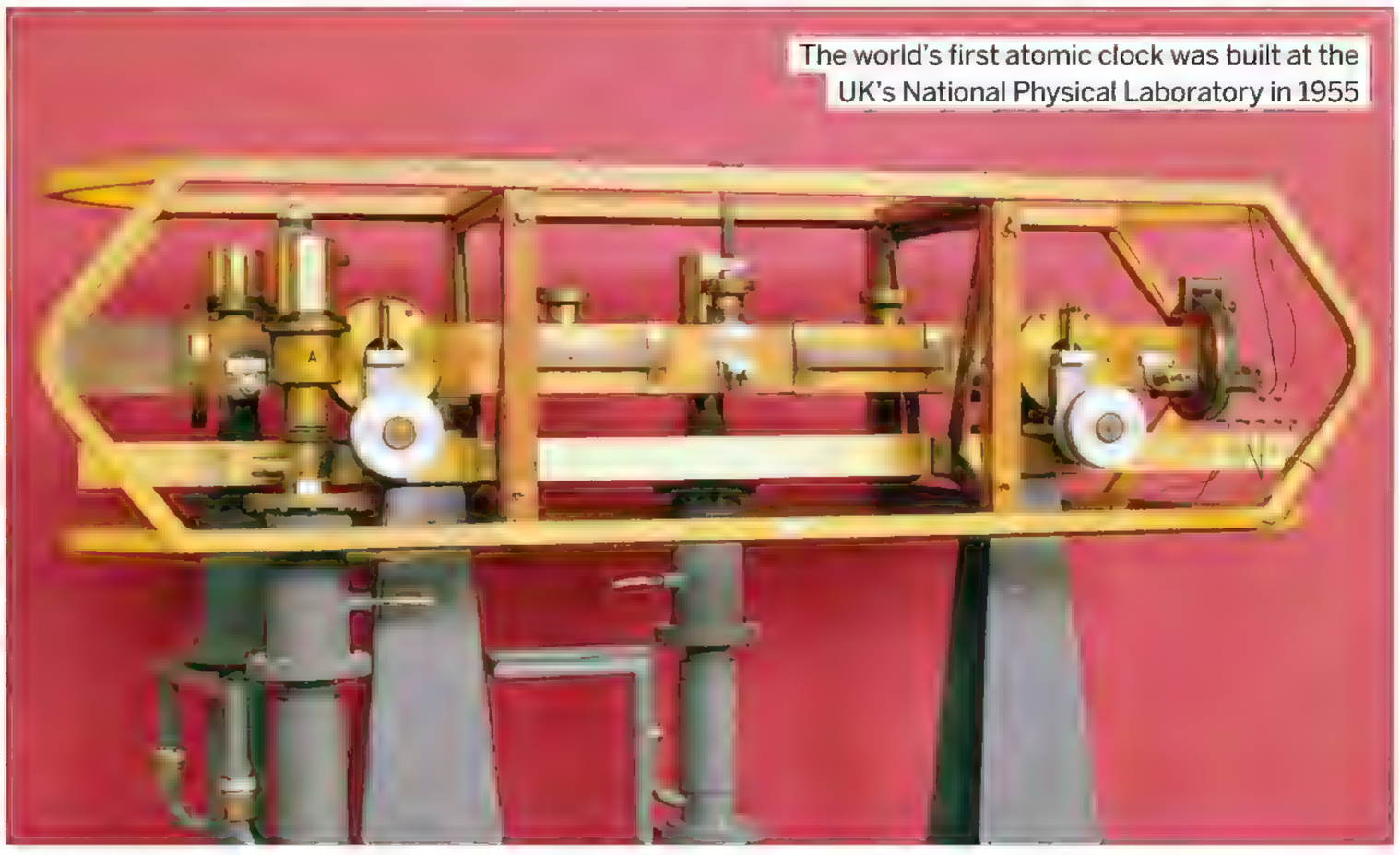
A montage of the various radio dishes making up the Event Horizon Telescope

"This technique requires an extremely precise knowledge of a signal's time of arrival at different dishes"

The Event Horizon Telescope's image of the black hole at the centre of our galaxy

OBSERVING BLACK HOLES

Many people will be aware of the spectacular images of supermassive black holes produced by the Event Horizon Telescope. What may be less well known is the key role played by atomic clocks in obtaining these pictures. To achieve the incredibly high resolution needed to see the region around the black holes, astronomers ideally needed an enormous radio telescope the size of Earth. What they actually used was the next best thing – individual dishes located in Spain, Arizona, Hawaii, Chile and Antarctica, all connected up in such a way as to act like a single giant instrument. Technically known as very-long-baseline interferometry, this technique requires an extremely precise knowledge of a signal's time of arrival at different dishes. In the case of the Event Horizon Telescope, this was provided by state-of-the-art atomic clocks called hydrogen masers.



The world's first atomic clock was built at the UK's National Physical Laboratory in 1955

ATOMIC CLOCKS

The world's most accurate timepieces, atomic clocks exploit the relationship between time and the frequency of electromagnetic waves. Expressed in hertz, frequency simply means the number of wave cycles per second. So if we know a wave's precise frequency, and can count the number of cycles, we can work out exactly how long a second is.

The first step is to create a wave of precisely known frequency – and that's where the atoms come in. The electrons inside an atom respond preferentially to certain frequencies, which cause them to jump from one energy level to another. To give a specific example, a frequency of 9,192,631,770 hertz triggers an important energy transition in caesium atoms. So if we fire a radio wave at a collection of caesium atoms and fine-tune its frequency until they all make this transition, we know we've got the frequency spot on. Add an electronic counter to count the number of wave cycles and tick off a second every time this reaches the magic number of 9,192,631,770, and we have our atomic clock.

Did You Know?

Caesium is the actual unit of the SI base quantity

The earliest atomic clocks focused on caesium for purely practical reasons, because that frequency of 9,192,631,770 hertz – or a little over nine gigahertz – was right at the upper limit of what was technically possible at the time. Today, however, it's possible to achieve much higher frequencies, and a whole new generation of atomic clocks is emerging that use elements such as strontium and ytterbium.

SUPER-ACCURATE TIMEKEEPING

RUBIDIUM CLOCK

ACCURATE TO

One second in 300 years

The smallest and cheapest atomic clocks are based on the element rubidium. They are widely used in mobile phone towers and TV transmitters.

HYDROGEN MASER

ACCURATE TO

One second in 300,000 years

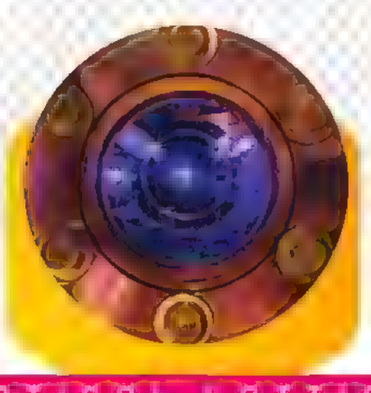
Hydrogen masers are specialised atomic clocks used in certain applications, such as the European Space Agency's Galileo satellites.

CAESIUM CLOCK

ACCURATE TO

One second in 100 million years

When scientists require high-precision timekeeping, they use caesium atoms. Caesium clocks have steadily improved in accuracy since their invention.



OPTICAL LATTICE CLOCK

ACCURATE TO

One second in 15 billion years

Powered by a laser and using strontium atoms on a 3D optical lattice, this is by far the most accurate timekeeping technology in use today.

What are SUPERFOODS?

How you fuel your body has a direct impact on your health, and some foods are considered far superior to others

WORDS **AILSA HARVEY**

Describing a food as a 'superfood' gives the impression that one berry or legume could be a miracle worker. In reality, we need a combination of lots of healthy foods to keep our bodies functioning optimally. Different items on your plate might be considered 'superfoods' due to high levels of a vital nutrient. This could be considered its power, but a team of food heroes is required to deliver all the nutrients your body needs.

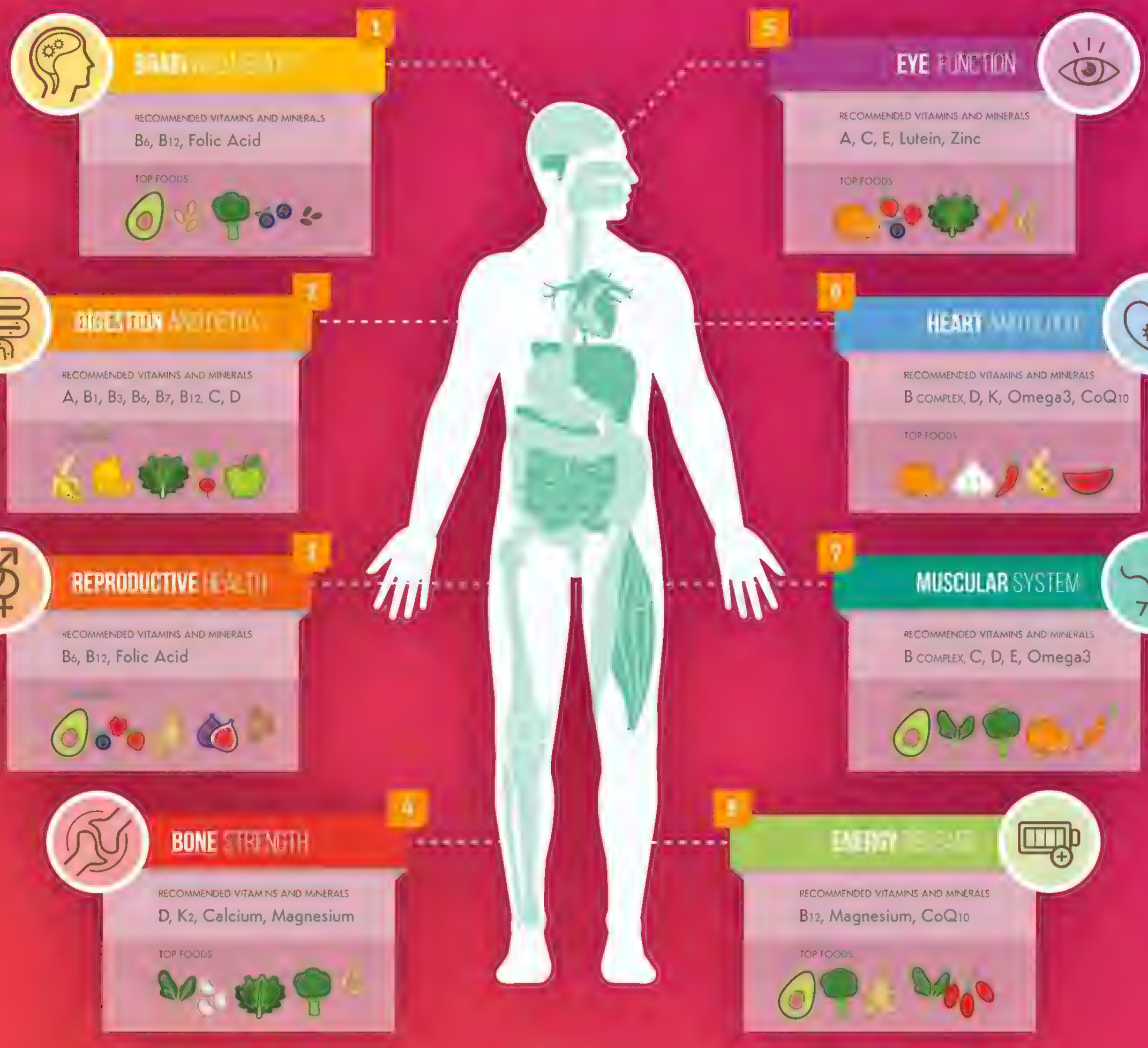
The term superfood doesn't have an official scientific definition – it's a general term for foods with an exceptional nutrient density or wide range of benefits. Often this term will be used on food product packaging to sell particular items or ingredients. Whole foods are the most worthy of the superfood title, being lightly processed or not at all. If a processed product claims to contain a superfood, the benefits of this ingredient are often cancelled out by the added sugar, salt and fat content.

The first food considered a 'superfood' was the banana. During a World War I advertising campaign, the United Fruit Company sold the fruit as a cheap and nutritious option for everyone. Soon after, the American Medical Association released scientific findings linking banana consumption to the relief of diabetes and celiac disease, before the cause of these conditions was better understood. It is true that a diet can work as a lifestyle treatment for some medical conditions, and the term superfood is still used to highlight some of the healthier and nutrient-packed options available.

Did you know?

BODY BENEFITS

How can superfoods be chosen to meet specific health goals?



1 BRAIN AND MEMORY

60 per cent of your brain is made of fat. Fats in nuts and fatty fish help in brain and nerve growth.

2 DIGESTIVE HEALTH

Ginger helps increase movement in digestion while also reducing gas to prevent bloating.

3 REPRODUCTIVE BENEFITS

Green, leafy vegetables contain the B vitamin folate. This vitamin supports healthy cell division & reproduction.

4 STRONG BONES

Sweet potatoes are high in potassium and magnesium. Magnesium helps harden bones, while potassium neutralises acid to prevent calcium leaching from bones.

5 EYE FUNCTION

Nuts and legumes, such as lentils and cashews, have omega-3 to prevent drying eyes and vitamin E to prevent age-related damage.

6 HEALTHY HEART

Beetroots contain high levels of nitrates, which work to dilate blood vessels and keep the heart pumping healthily.

7 MUSCLE MAINTENANCE

Eggs are high in protein, phospholipids, omega-3 fatty acids, cholesterol and vitamin D for muscle building.

8 ENERGY RELEASE

To keep energy levels high for long periods, avocados have potassium and healthy fats.

ESSENTIAL NUTRIENTS

THE VITAMINS AND MINERALS THAT SUPPORT HEALTHY BODILY FUNCTIONS

B6
Vitamin B6 helps manage mood regulation in the brain

B12

Fol

Ca

P

A

Fe

D
Without this vitamin the body can't absorb or regulate calcium well

FIVE NUTRIENT-DENSE FOODS

KALE
Kale can lower the risk of type 2 diabetes and heart disease

BLUEBERRIES
Blueberries have the most antioxidants of all common fruits and vegetables.

QUINOA
Quinoa contains twice as much protein as white rice

LIVER
100 grams of beef liver has over 2 000 per cent the daily recommended value of vitamin B12

SALMON
Salmon's high omega-3 content reduces the risk of heart disease, depression and arthritis

DID YOU KNOW? B vitamins are water soluble. They can't be stored in the body, so need to be a regular part of your diet

Fermented foods like kimchi are considered superfoods due to the beneficial bacteria, as well as the vitamins and minerals it contains

WHAT ARE THE DIFFERENT TYPES?

A diverse diet is key in maintaining health across the body. There are multiple superfood categories serving different biological purposes. The first superfood type is dark-green leafy vegetables, like kale and spinach. These leafy vegetables usually have high levels of calcium, iron, magnesium, vitamin C, fibre, zinc and folate. Many berries are also considered superfoods due to their high antioxidant, vitamin, mineral and fibre content. Berries also reduce the risk of inflammatory and immune conditions. Nuts and seeds are another type of superfood, usually high in protein, fibre and antioxidants, while whole grains, which are those that contain all the germ, endosperm and bran, hold onto all the vitamins and minerals that are usually lost in the refining process.

Leafy greens have low levels of carbohydrates, sodium and cholesterol

COMMON MYTHS

There are many myths surrounding how you should consume superfoods. For example, you might think that because they are so nutritious, you should eat superfoods in large quantities. But eating too much of anything cancels out the positive body response. By consuming too many antioxidants, instead of reducing the risk of disease, an overload can inhibit cells' defence mechanisms. Another common misconception is that superfoods also need to be super expensive. However, many cheaper food items have high nutritional value, from tinned beans packed with protein to tuna, carrots and eggs.

Not all superfoods are consumed as a whole foodstuff – some are taken as supplements

WHY VAPING IS BAD FOR YOU

How inhaling this flavoured aerosol affects your lungs and impacts the body

WORDS AILSA HARVEY

In the UK, 20.5 per cent of children between 11 and 17 years old had tried vaping as of 2023

Billows of fruity-flavoured mist are a common scent on today's city high streets. They plume from devices called electronic cigarettes, also known as vapes or e-cigarettes, and are exhaled from the mouths of young and old alike. But the liquid in vapes contains many harmful ingredients and a total of around 2,000 different chemicals. Despite the device's name, the mist that escapes vapes is inaccurately described as vapour. A vapour is a substance in gas form, while an aerosol contains small particles of liquid – called e-liquid in vapes – that are suspended in the air.

Did You Know?

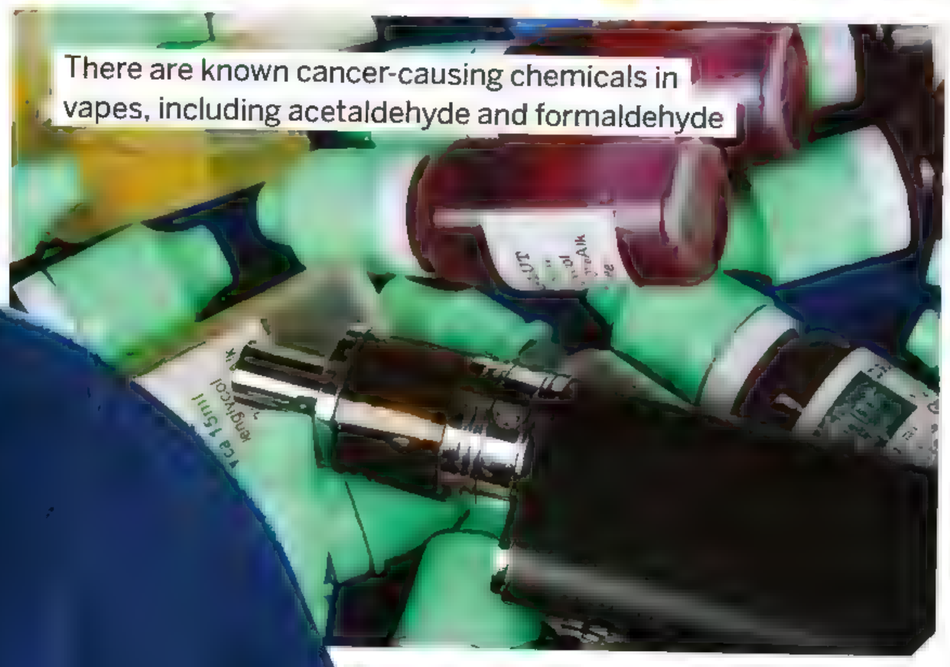
Although e-cigarettes were invented as a cigarette substitute, feeding nicotine cravings caused by smoking without exposing the body to many deadly toxins, vapes are a new craze that come with their own set of health hazards for a new generation of vaping addicts. Health agencies, such as those in the UK government, have previously misinformed people that vaping is a healthy alternative to smoking. Based on limited information about modern vaping devices and known ingredients, these groups promoted e-cigarettes as being 95 per cent safer than standard cigarettes. This information, which was intended to steer smokers away from tobacco products, has also steered younger non-smokers to these nicotine products.

The sweet-tasting vape flavours are marketed like candy, appealing to younger generations, while their hidden and potentially deadly chemicals can damage developing bodies. This includes your brain, which isn't fully developed until you reach your mid-20s – vaping can hinder this process. Some of the main psychological risks include severe

CONTENT CHECK

Unlike cigarettes, which burn tobacco, vapes only contain the nicotine that has been extracted from tobacco. This is a very addictive, toxic substance that raises your blood pressure, heart rate and adrenaline, and can hinder proper brain development in young people. Propylene glycol is a chemical added to vapes to help create mist when heated, but is known to cause respiratory irritation. It is commonly found in paint solvent and artificial smoke machines.

Not all chemicals found in the aerosol are present in the raw vape liquid. Those such as acrolein, a toxic chemical often used as a herbicide, is produced inside vapes when the device is heated and the flavouring chemicals begin to thermally decompose. Meanwhile, the chemical compound diacetyl is a yellow liquid that adds a buttery flavour to many vapes. Inhaling this chemical causes scarring to the lungs' air sacs.



There are known cancer-causing chemicals in vapes, including acetaldehyde and formaldehyde

INSIDE AN E-CIGARETTE

How does a vape heat liquid and produce an aerosol when inhaled?

1 MOUTHPIECE
This hollow tube connects to the cartridge, where the aerosol is produced. Inhaling through the mouthpiece activates the heating element and draws the mist into the mouth and lungs.

2 CARTRIDGE
The liquid, sometimes referred to as juice, is held in this compartment.

3 HEATING ELEMENT
This metal coil heats up the vape liquid, turning it into tiny airborne droplets. The particles absorb the heat energy, move vigorously and break molecular bonds that keep them in liquid form.

4 MICROPROCESSOR
Responsible for regulating much of the vape's technology, the microprocessor is activated by sensors to heat the liquid and keep temperatures within a safe consistent range.

5 SWITCH
Some vapes have automatic sensors for activation, while others have a switch to turn them on and off.

6 BATTERY
A built-in lithium-ion battery powers the device. Full charging takes three to four hours.

7 MIMICKING LED
The LED light at the bottom lights up to imitate a burning cigarette.

nicotine addiction, mood disorders and lowered impulse control. Those who start vaping when they're younger are more likely to pick up smoking habits later in life.

Many vapes are sold in disposable packaging that can leach hazardous chemicals into the environment when discarded carelessly. These include the plastics of the container and toxic compounds from the e-liquid remnants. The disposal of empty vapes into household bins can be just as problematic. The highly flammable lithium batteries inside the devices can easily start fires when crushed in refuse lorries. Through this process, they aren't recycled and their toxic metals enter landfills, contaminating surrounding ecosystems and water supplies. More than a million disposable vapes are thrown away every week – an indication of the scale of this increasing health and climate emergency.

CAN VAPING BE BENEFICIAL?

Vaping is considered the lesser of two evils when compared with tobacco. Cigarettes release thousands of chemicals into the body, and 70 of these are known to cause cancer. In the short term, it's better to take up vaping as a replacement to smoking rather than continuing smoking. Vapes are one of the most useful tools for stopping smoking. When an adult switches from smoking to vaping, it's also normal for them to vape more frequently than they smoked. This isn't always as harmful, as toxins in their body can still be reduced. Nicotine levels in vapes vary and don't contain the same chemicals, like tar and carbon monoxide, so the only benefit of vaping is to wean someone off their nicotine addiction by reducing the strength until they quit.

Unlike vapes, cigarettes turn healthy lungs (left) into tar-covered black tissue (right)

VAPING VS SMOKING

Discover the known and potential health impacts of inhaling vape aerosol compared with inhaling cigarette smoke

1 INFLAMMATION
Flavouring agent diacetyl causes inflammation in the branches of the lung's airways. A 2023 study suggests vapers suffer from more inflammation than smokers.

3 ACCELERATING CELL DEATH
Cell death occurs five times as often when vaping without nicotine, and ten times as much with nicotine.

11 MUCUS THICKENING
Vaping dehydrates the airways and causes thick mucus.

15 SIGNS OF EMPHYSEMA
Some studies have linked vaping with emphysema. Emphysema is damage to the lungs' air sacs, reducing gas exchange in and out of the organ.

9 IMMEDIATE INFECTIONS
Long-term infections caused by vaping are yet to be fully understood. More immediately, vaping decreases the production of antiviral protein SPLUNC1, increasing the risk of respiratory infections like the common cold.

13 SMALL AIRWAY OBSTRUCTION
The lungs' small airways are impeded by vaping, resulting in asthma-like symptoms. The extent of further damage isn't well studied.

19 FATTY IMMUNE CELLS
E-liquid contains oily substances that cigarettes lack. The fats are engulfed by immune cells called macrophages. The presence of these lipid-filled cells causes inflammation.

17 TUMOUR STUDIES
Vapes don't contain cancer-causing tobacco, and there's no significant evidence that vaping causes tumour growth.

7 DNA DAMAGE
E-liquid may stop DNA repair mechanisms, leading to DNA damage.

5 GENE EXPRESSION
E-cigarette aerosol changes the expression of non-coding RNA molecules without altering the DNA sequence. Non-coding RNA controls cell function without directly making proteins.

"Their hidden and potentially deadly chemicals can damage developing bodies"

2 CHRONIC INFLAMMATION
Smoking is known to cause severe inflammation due to containing more lung-irritating compounds like tar and carbon monoxide.

1 IRREVERSIBLE CELL DEATH
Smoking causes more extensive cellular damage. When cells of the lungs' air sacs die, they can't regain function.

12 MUCUS BUILD UP
Smoke increases the permeability of lung tissue, which leads to too much mucus being released.

10 SEVERE INFECTIONS
Cigarette smoking is known to cause bronchitis, pneumonia and chronic obstructive pulmonary disease (COPD), and increases the risk of contracting tuberculosis.

6 GENE SUPPRESSION
Smoking may weaken the genes that control tumour growth.

8 DNA MUTATIONS
One packet of cigarettes holds enough harmful compounds to cause two mutations in the DNA of lung cells.

14 AIRWAY OBSTRUCTION
COPD is a disease that restricts airflow. 80 per cent of COPD deaths are due to smoking.

16 CAUSE OF EMPHYSEMA
Smoking is the main cause of emphysema – smokers are six times more likely to develop it than non-smokers.

18 CANCER-CAUSING
Tobacco in cigarettes can damage DNA. This causes cells to begin to grow out of control and produce tumours in the lungs.

Did you know?
Nicotine itself doesn't cause cancer or heart disease

5 FACTS HIDDEN DANGERS

1 MISLEADING LEVELS
E-cigarette packaging can be misleading. Research shows that around half of the labels on e-cigarette containers display levels that don't actually match the contents.

2 SECOND-HAND EXPOSURE
Inhaling second-hand aerosol from others vaping in the home is linked to shortness of breath in young adults.

3 CARDIOVASCULAR CHAOS
Using vapes more than five times a week and for at least three months is enough to cause blood vessels to stop working properly and lead to cardiovascular disease. Nicotine increases your chances of suffering a heart attack.

4 MENTAL HEALTH
In a study by the American Heart Association, anxiety was 20 per cent more prevalent in vapers. 50 per cent of those who vaped experienced symptoms of depression as opposed to 25 per cent of non-vapers.

5 ALTERING IRRITANTS
Not all of the toxins are labelled on a vape's packaging. Those that are produced during the heating of the ingredients are often missed off the list.

Workers at a factory in Shenzhen, China, make e-cigarette pods for vaping manufacturer KangerTech

WHERE E-CIGARETTES ARE MADE

Around 90 per cent of vape pens are manufactured in China by companies owned by entrepreneur Zhang Shengwei. Every year, hundreds of millions of vapes are shipped from China to the UK and US, but many of these factories lack quality control. This results in thousands of harmful chemicals entering the products and the lungs of those that use them. For example, studies have discovered that some vape aerosols have four times more of the hazardous metals nickel and chromium in them than standard cigarette smoke. As vapes don't contain tobacco in its full form, the Chinese tobacco authority that regulates cigarette manufacturing and other similar products in China doesn't monitor these factories. When vapes became popular, many countries struggled to categorise the devices. They weren't classed as drugs, food or tobacco. Today the Medicines and Healthcare products Regulatory Agency (MHRA) in the UK and the Food and Drug Administration (FDA) in the US regulate vapes.

Did you know?

In 2021, thousands of harmful chemicals were found in vapes

WHAT IS EVALI?

Recognised as hazy spots on the lungs in a chest X-ray and with symptoms that include shortness of breath, fever and chest pain, EVALI is a severe lung disease caused by vaping. The full name of the illness is e-cigarette or vaping use-associated lung injury, and vitamin E acetate is thought to be the main substance in e-cigarette liquid that causes this lung damage.

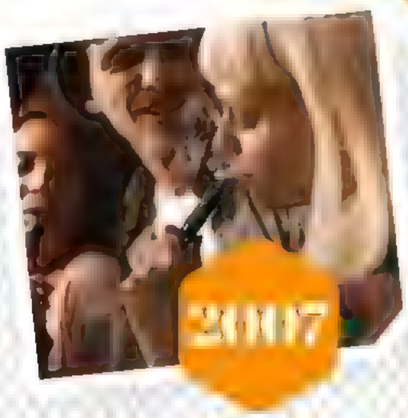
The disease can crop up quickly, affecting people soon after they start vaping, or it can build up over a longer period of vaping. 90 per cent of those who develop EVALI need to go to hospital, and it can be deadly in the most severe cases. Young people under the age of 35 are believed to be most at risk of EVALI. The condition has only been reported in the last few years, so scientists are researching the disease to discover how to reverse the damage it causes.

Healthy parts of the lungs usually appear dark on X-ray scans

HOW VAPES EVOLVED

Controversy has surrounded vaping since it was invented

2003 Chinese pharmacist Hon Lik invented the modern e-cigarette to remove the smoke from the act of smoking. He was a smoker himself, and lost his father to lung cancer.



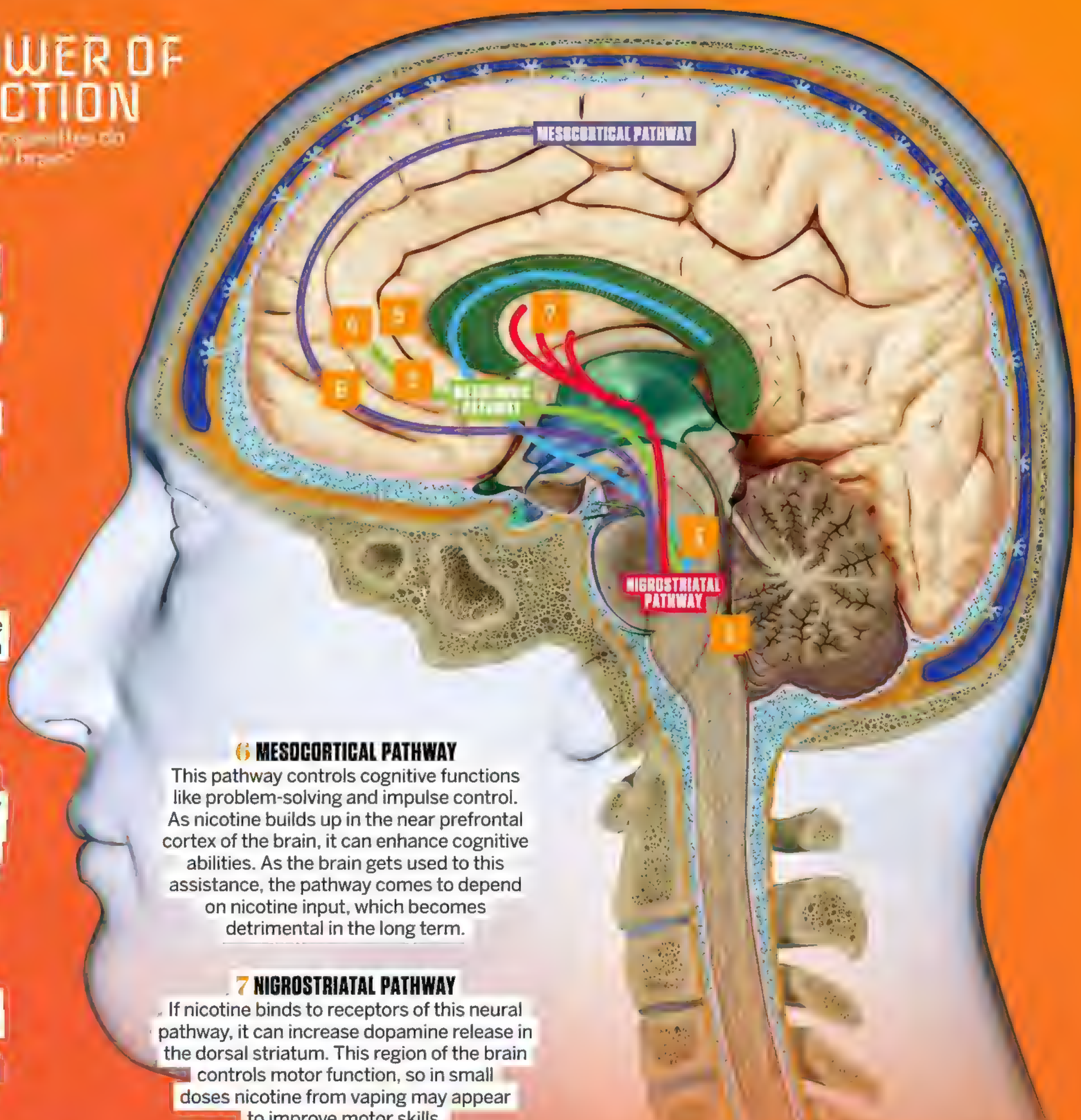
2007 Vapes entered the global market and the World Health Organization expressed health concerns.

2010 2010 is considered the year in which vaping increased greatly in popularity around the world.

2014 Advertising and packaging became targeted at adolescents' tastes, sparking safety concerns. The term 'vaping' became popular in this year.

THE POWER OF ADDICTION

What do e-cigarettes do to your brain?



1 BLOOD-BRAIN BARRIER
10 to 20 seconds after inhaling nicotine, it crosses the blood-brain barrier into the brain.

2 MESOLIMBIC PATHWAY
This neural circuit releases the feel-good chemical dopamine into the body.

3 VENTRAL TEGMENTAL AREA (VTA)
Neurons in this area have nicotine receptors. When the molecules bind to them, the mesolimbic pathway is activated.

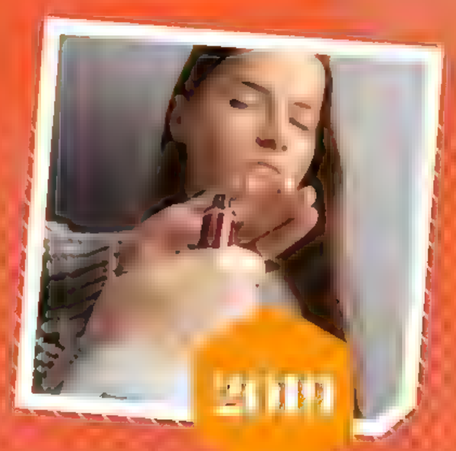
4 NUCLEUS ACCUMBENS
The mesolimbic pathway connects the VTA to this area of the brain, where dopamine is released.

5 REWARD AND REINFORCEMENT
Dopamine, released here, creates feelings of pleasure in the brain. As the brain learns this feeling, it seeks further reward from more nicotine hits.

6 MESOCORTICAL PATHWAY
This pathway controls cognitive functions like problem-solving and impulse control. As nicotine builds up in the near prefrontal cortex of the brain, it can enhance cognitive abilities. As the brain gets used to this assistance, the pathway comes to depend on nicotine input, which becomes detrimental in the long term.

7 NIGROSTRIATAL PATHWAY
If nicotine binds to receptors of this neural pathway, it can increase dopamine release in the dorsal striatum. This region of the brain controls motor function, so in small doses nicotine from vaping may appear to improve motor skills.

2016
In the US, the FDA gained authority to regulate tobacco and vape products on 8 August.



2019
EVALI was officially identified. In the US alone, there were 2,051 cases and 39 deaths reported in four months.

2020
In the US, the legal age for purchasing vaping products was raised from 18 to 21.

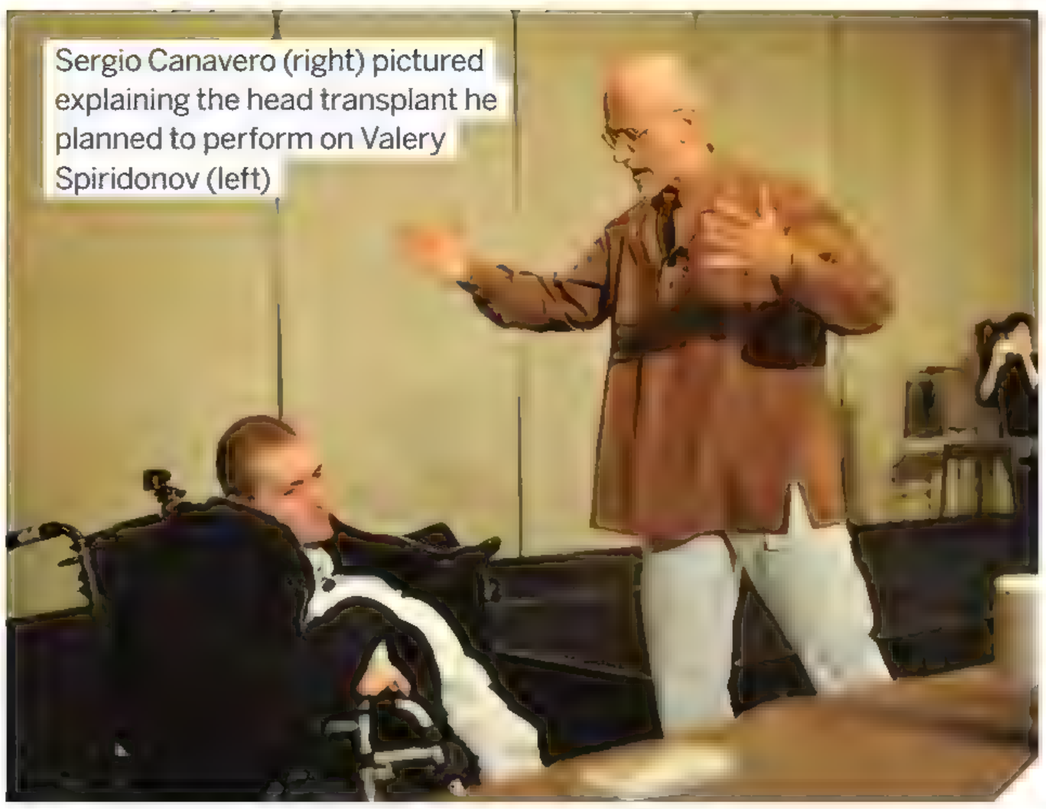
2024
Amid the COVID pandemic, respiratory health entered the spotlight, re-igniting the debate around the dangers of vaping.

Following a 2023 proposal to ban cigarettes for those born in 2009 or later, the UK announced plans to ban all disposable vapes.

ARE BRAIN TRANSPLANTS POSSIBLE?

This controversial surgery has complicated technicalities to consider before our body's most sophisticated organ can be switched out

WORDS **AILSA HARVEY**


Sergio Canavero (right) pictured explaining the head transplant he planned to perform on Valery Spiridonov (left)

Before the first successful heart transplant in 1967, the idea of removing this life-sustaining organ from a body and replacing it with someone else's was thought impossible. Now, around 3,500 heart transplants are carried out each year. Can the same happen for those with healthy brains but a body that's failing them?

Unlike the heart – the function of which scientists have a great understanding of – the brain is considered the most complex thing in the universe. It contains trillions of cellular connections, efficiently controlling the way you think, feel, remember, move and the way you perceive the world. The brain, which is connected to the spinal cord to make up the central nervous system, would need to be cut away from the spinal cord for a transplant. The greatest challenge following this irreversible act is to precisely reconnect the blood vessels, nerves and other tissues quickly enough that vital brain tissue doesn't die, and do it with such precision that the individual wakes up from the procedure with their mental and physical abilities uncompromised.

For now, the technical and ethical challenges that come with relocating a brain keep the reality of such a transplant in the distant future for most. But this hasn't stopped all neurosurgeons. In 2017, Italian neurosurgeon Sergio Canavero claimed that he could successfully carry out a head transplant. Instead of isolating just the brain, the surgeon planned to cut off the head of a Russian man called Valery Spiridonov.

Spiridonov volunteered to be the first person to receive this transplant, as he suffered from a severe muscle-wasting condition that destroyed nerves in the spinal cord. This left him wheelchair-bound and willing to undergo the reconnection of his head onto a new body and spinal cord. The date was scheduled in 2017 – but it didn't take place. The case highlighted the ethical concerns of using vulnerable patients in high-risk experimental procedures. Neurosurgeons like Canavero continue to work on brain transplant research, while others focus more on the future technologies that are emerging to improve patients' quality of life with robotics. This involves brain-machine interfaces that replace the brain's communication with the central nervous system to keep the most complex biological systems intact.

Did you know?

There are 100 billion neurons in a mature human brain

DANIEL HOLSGROVE

A consultant neurosurgeon from Salford Royal Hospital explains the complications of a brain transplant procedure

What elements of brain transplants are possible?
I think lots of the technical aspects are already done in other types of surgery, for example reconnecting blood vessels. You could reconnect a blood vessel from donor and recipient. There are ways of doing that, and that's done in lots of surgeries already.

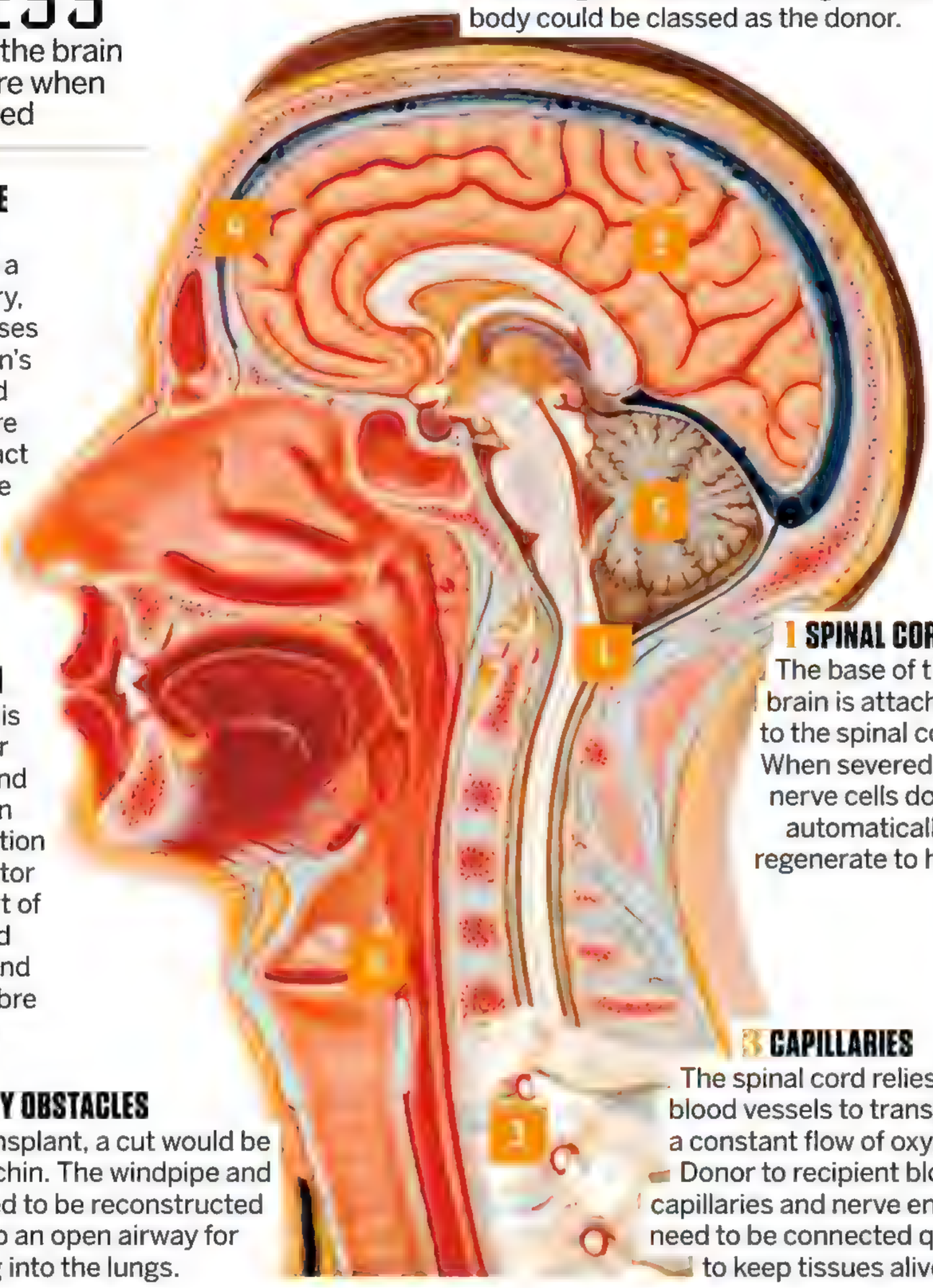
What would be the most difficult part?
The biggest challenge is in relation to the spinal cord, and connecting the donor and recipients' brain and spinal cord, depending on where exactly you choose to make the division. Although it's been proposed there are certain technologies that could help, there's no proven way of reconnecting a spinal cord in a way to maintain or restore function in a way that would be useful.

Wouldn't transplanting a whole head onto another body be a lot easier than a brain transplant?
Just transplanting the brain means you've also had to cut all the nerves that go from the brain to around the head and neck, so that makes it more complicated. If you were to transplant a whole head, then you have the issues with the blood vessels, spinal cord, trachea and oesophagus. However, the nerves connecting the brain to the eyes, for example, would be left intact. The nerves that go directly from the brain to the cranial nerves and directly to the areas around the face and neck would be left intact. That would be more straightforward in that regard.

DID YOU KNOW? A full-head transplant has only ever been carried out on a cadaver

ORGAN ACCESS

How parts of the brain and head fare when detached



1 FRONTAL LOBE
Partial brain transplants risk a frontal lobe injury, which in some cases can alter a person's personality and make them more argumentative, act and speak more impulsively.

2 DONOR OR RECIPIENT?
In a brain transplant, the brain being transplanted would carry a person's thoughts. In reverse to standard organ donation, the organ's new body could be classed as the donor.

3 CAPILLARIES
The spinal cord relies on blood vessels to transport a constant flow of oxygen. Donor to recipient blood capillaries and nerve endings need to be connected quickly to keep tissues alive.

4 SPINAL CORD
The base of the brain is attached to the spinal cord. When severed, its nerve cells don't automatically regenerate to heal.

5 CEREBELLUM
This brain area is responsible for motor control and coordination. In brain transplantation for regaining motor function, this part of the brain would need accurate and intricate nerve fibre connections.

6 MANY OBSTACLES
In a full-head transplant, a cut would be made below the chin. The windpipe and oesophagus need to be reconstructed exactly to keep an open airway for breathing into the lungs.

PARTIAL TRANSPLANTATION

The core goal of a brain transplant is to keep a person's mind the same, but provide a new body with renewed functionality. As each section of the brain has its own roles, are partial brain transplants possible? A large part of what shapes your personality are your memories, so if a brain transplant became feasible, you would want to keep hold of as many of these as possible. For this outcome, a partial brain transplant is ruled out. The hippocampus, a complex brain structure near the centre of the brain, is regarded as the memory centre of the brain. However, in reality memories are formed and stored in multiple areas. Trying to transplant part of the brain risks cutting off neural connections between memories and destroying them.

Pyramidal neurons process external signals and motor control

What could happen if it went wrong?
I think there are huge psychological aspects to it. Without that spinal cord connection, there would be a risk of brain injury through ischemia – lack of blood flow and oxygenation – during transplantation, so you could easily harm the brain. You are taking a healthy brain to connect it to a healthy body where the body has failed. But you risk causing an injury to the brain, and there's a risk that you could have someone sort of locked in, which is when they may maintain brain function but are unable to communicate or have a functioning body.

What happens when you remove a brain from a body?
If you cut off the blood supply to parts of the brain, the neurons will start dying after about three minutes, but you can extend that period of time through various techniques. You can give medication, like a very deep form of anaesthesia, to reduce the brain's metabolic activity so that the activity within the separate cells is reduced. Often, this makes that three minutes extend to seven minutes, for example, before you start seeing changes in the brain's electrical activity to suggest that the brain is becoming impacted by the reduced blood flow to it. Other procedures can intentionally lower the brain's temperature that can extend it further into the region of 20 to 30 minutes, potentially. However, we're not at the stages where you could put a brain in an ice box and transport it across the country.

"There are huge psychological aspects to it"

Will the advances in technology improve the likelihood of brain transplants becoming commonplace in the future?
I think technological advancements such as exoskeletons that can be controlled by someone's thoughts, using wearable or implanted sensors or stimulators to help send the messages to the nerves to get people moving is likely to make transplantation irrelevant before it's even begun.

ORCHESTRAL ARRANGEMENT

How the instruments of an orchestra are arranged in tandem with our brain functions

WORDS SCOTT DUTFIELD

Why are the brass in the back and strings at the front of an orchestra? The reasons for the positioning of an orchestra all relate to how the brain 'hears' different sounds. A modern symphony orchestra typically consists of around a hundred different players performing with a wide variety of instruments, including those in the woodwind, string and bass families. All of these produce different pitches that work together to create a harmonious sound. In music, pitch refers to the length of a sound wavelength produced by an instrument, which correlates with the size of the instrument. For example, deep long sound waves emanate from larger instruments such as tubas and cellos, whereas higher pitches come from the short sound waves of a viola or flute.

When instruments come together to form an orchestra, the deeper pitched instruments are positioned on the right side when viewed from the audience, and the higher pitched instruments are on the left. The orchestra is orientated this way according to our brain's preferences. Within each of the brain's two hemispheres is a region known as the auditory cortex, which interprets signals generated from the ears. To make things complicated, each auditory cortex is wired to the opposite ear – the right auditory cortex is fed by the left ear and the left auditory cortex listens through the right ear. And while each ear picks up the same sounds, studies have found that the right auditory cortex processes lower pitches better, while the left is handier with high pitches.

The arrangement of an orchestra mimics this crossover of the auditory cortices. Built to benefit the players, not the audience, high-pitched instruments are placed on the right side from the players' perspective so that they are better heard, and vice versa for the lower pitched tones. The distance an instrumental section is from the front depends largely on their size and volume. Louder instruments such as percussion drums or brass tubas are placed at the back of the orchestra to prevent them from blocking the softer, quieter sounds of the strings at the front.

Did you know?

'Orchestra' is from the Greek for 'dancing place'

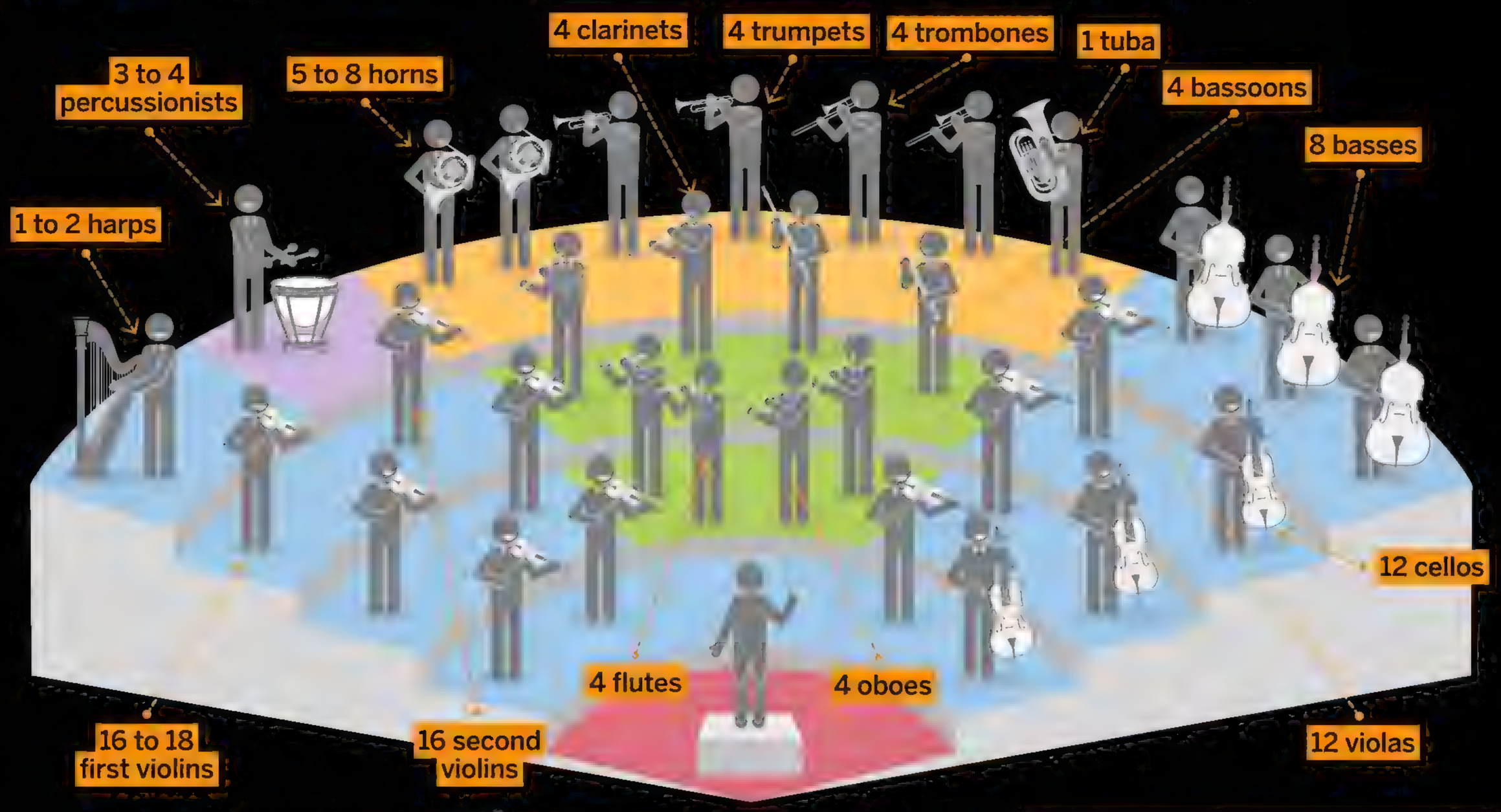
A portrait of Mozart

THE MOZART EFFECT

According to research conducted by London Metropolitan University in 2020, listening to Mozart can improve your short-term memory. The Mozart effect was first described in 1993 when an article in the journal *Nature* suggested that listening to Mozart's music could improve IQ test scores. Since then, many studies have been carried out to investigate the science behind his symphonies, including its role in short-term memory. In the 2020 study, researchers asked a group of 84 participants to recall a set of words following a minute-long sound clip of Mozart's *Eine kleine Nachtmusik*. They found that Mozart's music did enhance word memory. Having run *Eine kleine Nachtmusik* through sonograms and spectrograms to visually examine its frequency and sound, the researchers concluded that a positive effect on recall may be linked to the similarity between Mozart's music and the structure of words and sentences.

The auditory cortex is found in the two temporal lobes of the brain

DID YOU KNOW? The world record holder for largest orchestra is El Sistema, with 8,573 instrumentalists and singers



ALLOCATING INSTRUMENTS

How an orchestra is arranged to make the most out of its sound

CONDUCTOR

Front and centre of any orchestra is the conductor, whose job it is to set the tempo and volume for the music and maintain harmony between the players.

BRASS

The loudest instruments within an orchestra are found in the brass section, placed at the rear. Trombones can reach up to 114 decibels, whereas violins at the front of the orchestra can reach up to 95 decibels.

STRINGS

The string instruments in an orchestra range from the high-pitched sounds of violins on the left to lower pitched basses on the far right. Although they might look similar, violas are tuned one-fifth lower than a violin, hence violins begin on the left side of the string section and the violas end on the right.

WOODWINDS

The woodwinds sit in the centre of an orchestra and have the higher pitched piccolos and flutes on the left and the lower pitched oboes and bassoons on the right. Woodwinds also sit in front of the brass section to ensure they aren't drowned out by the powerful volume of trumpets and tubas.

PERCUSSION

Percussionists play a variety of different instruments in this section, including timpani drums, cymbals and xylophones. Similarly to the brass section, percussion instruments like timpani drums can produce a louder sound than other instruments, at around 100 decibels, so sit at the back of the orchestra.

THE FIRST ENSEMBLE

Although instruments have been around for thousands of years, it wasn't until around 1600 that Italian composer Claudio Monteverdi assembled the first orchestra. Playing the score to his 1607 opera *L'Orfeo*, Monteverdi's orchestra brought 40 instruments together, including bowed strings, harpsichords and trumpets. For the first time, Monteverdi used an orchestra to elevate moments in the opera with specific instruments. His orchestral innovation began a rise in popularity and laid the groundwork for other orchestral pioneers, such as Johann Sebastian Bach.

The funeral notice following Claudio Monteverdi's death in 1643

SCIENCE

WHY WATER HAS 'SKIN'

How the surface tension of water forms a film

WORDS AILSA HARVEY

Water's surface tension holds molecules together, resisting the force of the emerging swimmer

Just as human skin produces a shield for our bodies, a volume of water forms a barrier at its surface that resists force and holds water molecules together. This is called surface tension and can be seen when a small object or insect lands on water. Instead of cutting sharply through the water, the object will first bend the surface, as if the water was covered with cling film, although the liquid's skin-like surface has an identical composition to its main body. The difference is that the chemical bonds connecting molecules at the surface are much stronger than those beneath.

Did You Know?

Mercury's surface tension is 10 times greater than water's

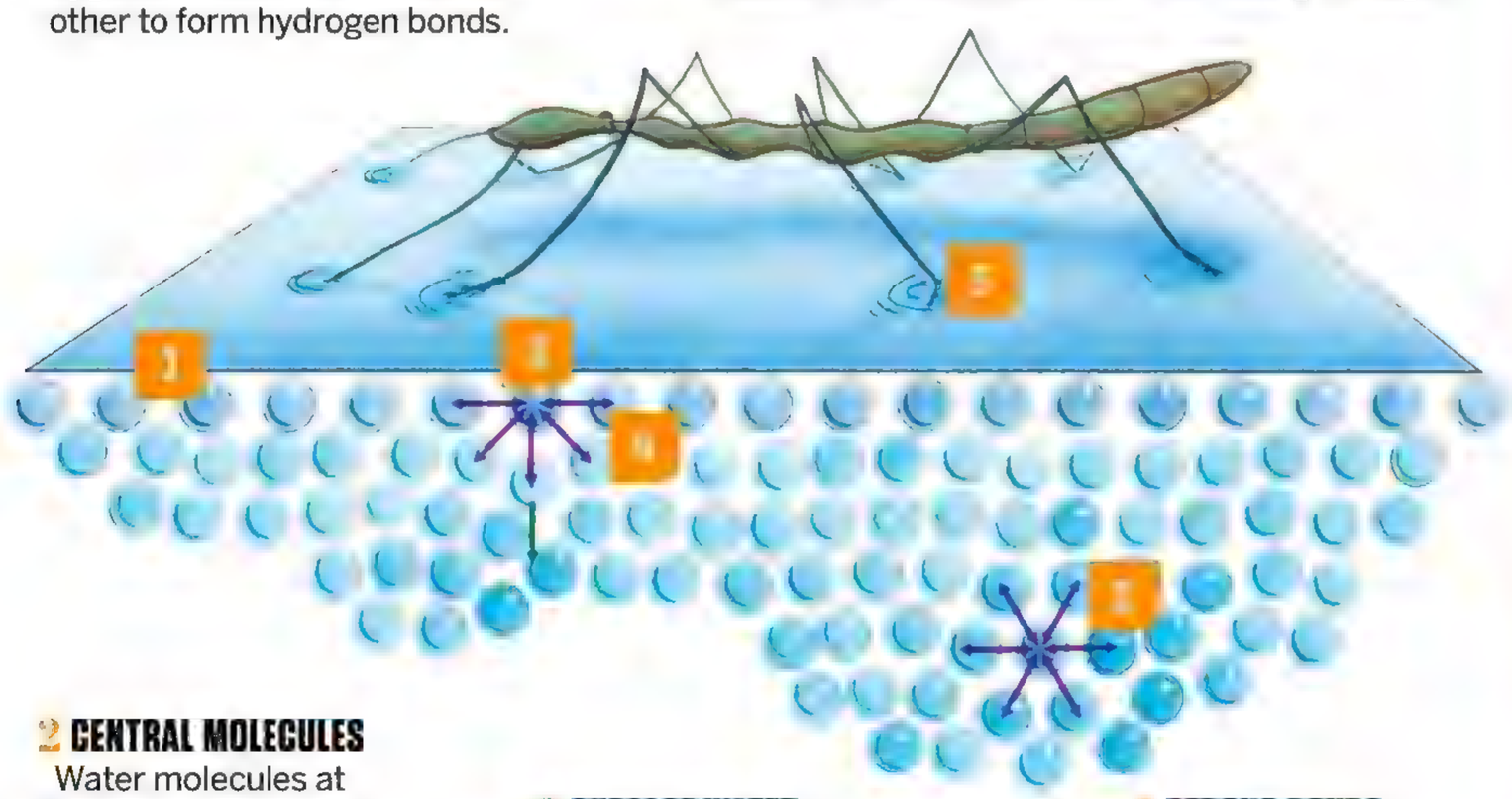
Surface tension is also responsible for forming the shape of rain droplets. Instead of scattering over surfaces evenly, the molecules of water group together to form droplets when they land. Smaller raindrops have a stronger surface tension than larger ones. When falling through the air, water droplets become less spherical and flatten at the bottom as air pushes against them. The raindrops fall to the ground and collide with other droplets on their journey, becoming larger. This continues until the surface tension becomes too weak to hold the droplet's shape and the molecules disperse.

MOLECULAR BREAKDOWN

When an insect lands on water, it's supported by hydrogen bonding

1 WATER MOLECULES
Water molecules contain positive hydrogen atoms and a negative oxygen atom, which attract each other to form hydrogen bonds.

5 STRONGER SUPPORT
The stronger bonds at the surface remain intact under the pressure of light weight, enabling insects like water striders to walk on water without falling through.



2 CENTRAL MOLECULES
Water molecules at the centre form many bonds with the molecules completely surrounding them.

3 SURFACE WATER
Molecules at the surface can only bond with those next to and below them.

4 STRONG BONDS
Due to there being fewer hydrogen bonds at the surface, those that form are stronger.

BREAKING THE TENSION

Some factors alter the strength of water's surface tension. For example, as the water's temperature decreases, the surface tension increases, while warmer temperatures weaken the 'skin'. This is because the molecules have more energy at higher temperatures. They move faster and lose their ability to stay connected for as long. Adding chemicals to water also lowers surface tension. Soap molecules have one hydrophilic end that is attracted to water and one hydrophobic end that repels it. When in contact with water, the hydrophilic end pulls water molecules away from each other while the hydrophobic end prevents the body of water mixing cohesively.

The cold slow down water molecule movement, so stronger bonds form at its surface, like morning dew on grass

HOW SEA GLASS IS MADE

This ocean process turns household trash into sea treasures

WORDS **SCOTT DUTFIELD**

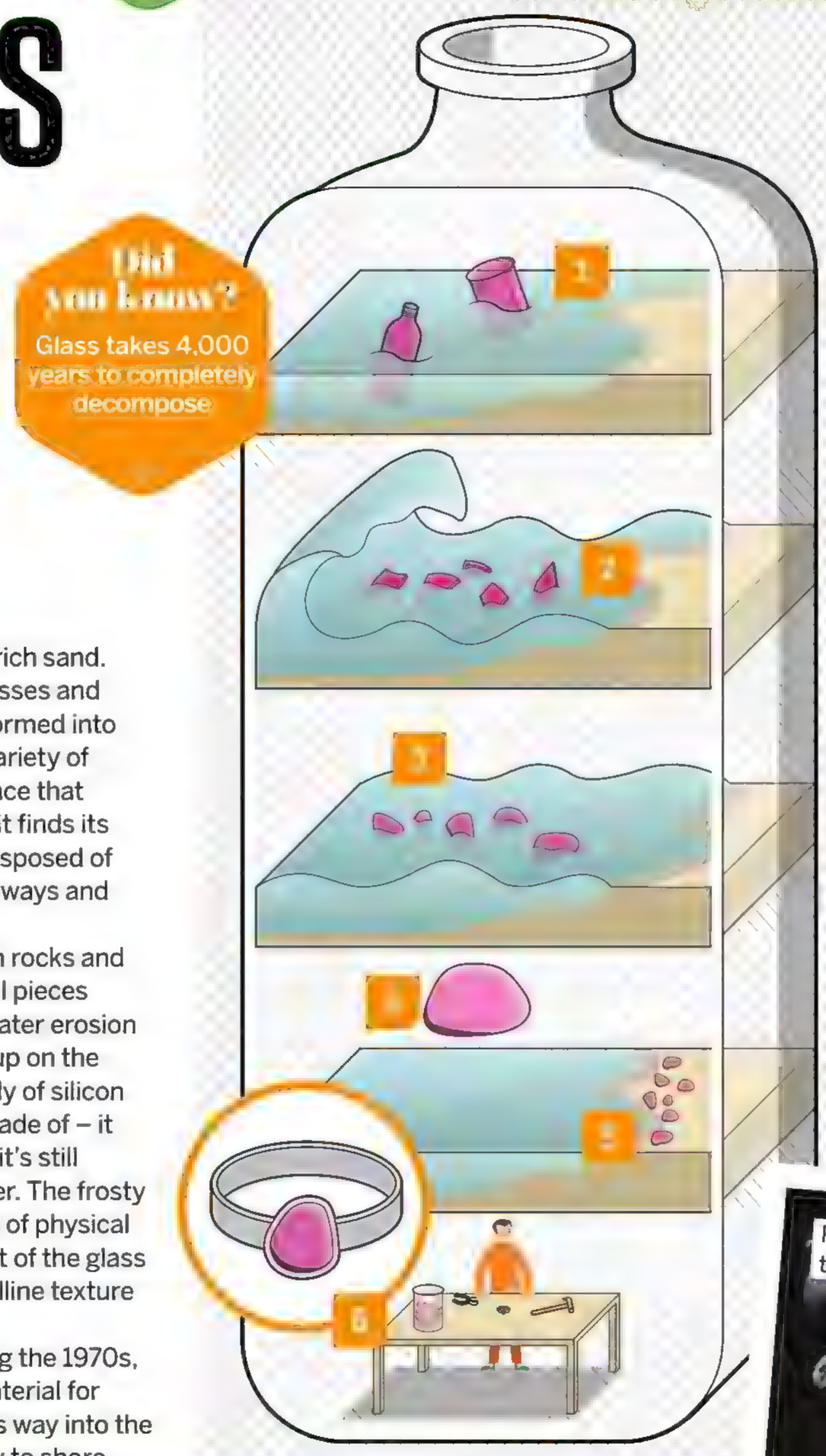
All glass starts its journey as silicon-rich sand. Through a series of chemical processes and heating in a furnace, sand is transformed into molten glass and is shaped into a variety of different bottles, ornaments and glassware. Once that glassware is no longer in use and is discarded, it finds its way to a recycling centre to find new life or is disposed of through a landfill, where it can creep into waterways and eventually the ocean.

When it passes into the ocean, collisions with rocks and other hard objects break up the glass into small pieces before decades or even hundreds of years of water erosion create small, smooth glass pebbles that wash up on the beach. Because glass is made up predominantly of silicon dioxide – the same compound that quartz is made of – it shares this mineral's hardy qualities. However, it's still susceptible to the chemical erosion of salt water. The frosty texture of sea glass is not only caused by years of physical abrasions, but the hydroxide that is leached out of the glass by the water's high salt levels, forming a crystalline texture on its surface.

Since the increase of single-use plastic during the 1970s, glass has taken a backseat as the preferred material for packaging, meaning that less glass is finding its way into the ocean and fewer sea glass pieces find their way to shore.

SHAPING JUNK GEMSTONES

From waste glass to sought-after stones



Did you know?

Glass takes 4,000 years to completely decompose

1 WASTE
Sea glass starts its journey as discarded glassware that's been tossed in the ocean.

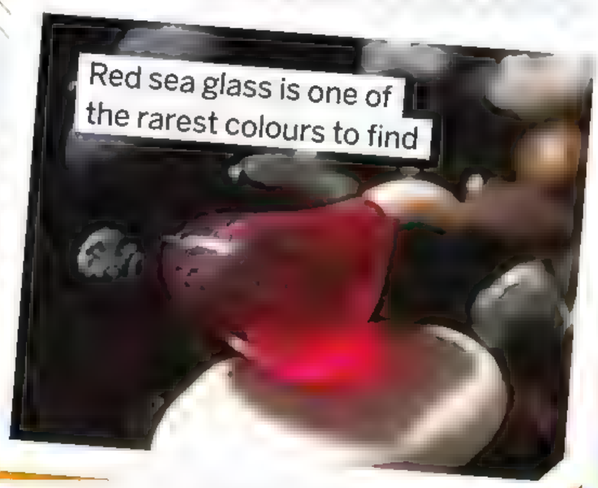
2 BROKEN APART
Under the power of the ocean, glass tumbles through water, collides with rocks and is broken apart.

3 DRAGGED
The angular pieces of glass are dragged along the seafloor along with the tides, rounding off their sharp edges in the process.

4 FROSTING
Over time, the salinity of the ocean water and the abrasion the glass experiences cause the surface to frost over.

5 WASHED UP
Sea glass eventually washes up on the shoreline.

6 ARTWORKS
Jewellers and artists often collect sea glass to incorporate it into their work.



Red sea glass is one of the rarest colours to find

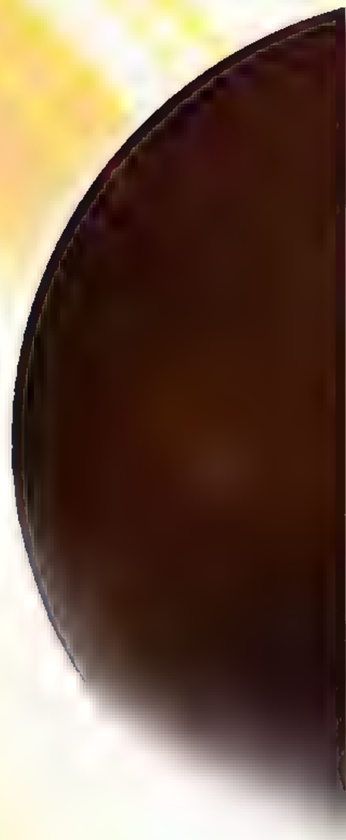
The Fort Bragg sea glass beaches are made of three 'sites', with site two and three boasting the most glass

BEAUTIFUL BEACH DEBRIS

The beaches at Fort Bragg in California were once used as a dumping site for locals to discard their rubbish, including heaps of glass waste. By 1967, the beach was overflowing with rubbish and the locals sought new dumping grounds, leaving the trash to the mercy of the elements. Over time, the heaps of rubbish began to dwindle as people rifled through the piles to repurpose metal waste and biodegradable materials rotted away. Eventually, all that remained were glass and ceramics, which were claimed by the ocean. As decades passed, continual bombardment by ocean waves smoothed the glass and rounded its edges, transforming the once-sandy beach into a floor of frosted sea glass. The Fort Bragg Glass Beach is now under the protection of MacKerricher State Park, and removing any of the glass is prohibited.

SPACE

BIGGEST BLACK HOLES IN THE UNIVERSE



WORDS ANDREW MAY

There's a giant black hole with the mass of 4 million Suns at the centre of the Milky Way. But that's still tiny compared to its counterparts in other galaxies

DID YOU KNOW? Atomic bomb scientist Robert Oppenheimer worked on black hole theory prior to World War II

Black holes are the most extreme astrophysical phenomena in the universe. And there's a good chance they're the best known, too. Not everyone has heard of neutron stars, planetary nebulae or brown dwarfs, but most people have come across the idea of a black hole, even if it was only in a science-fiction film. Part of the fascination lies in the way black holes seem to break – or at least twist beyond recognition – all the common-sense laws of physics. Looked at more closely, though, they're really just an inevitable consequence of these laws.

As a theoretical concept, black holes first made their appearance when scientists were thinking about gravity, particularly in the context of large objects such as stars. Gravity is a force that acts between particles of matter, tending to pull them closer and closer together. In everyday objects in the world around us, the force of gravity is counterbalanced by other physical effects such as electrostatic and nuclear forces – with the result that things maintain a finite size rather than collapsing down to a point. The same is true of stars like the Sun, where gravity is counteracted by fluid pressure. Even in an ultra-compact star like a white dwarf, where a mass similar to that of the Sun is squashed down to a planet-sized volume, there are other more exotic forces that come into play to stop them collapsing forever.

13 BILLION LIGHT YEARS
The most distant known black hole is nearly at the edge of the observable universe

By the middle of the 20th century, however, scientists knew there was an upper limit to the amount of gravity that these exotic forces could resist. If a star was sufficiently massive to start with, it would eventually collapse all the way down to an infinitesimally small point. All the original mass would still be there, but compressed down to a state of infinitely high density. This sounded so impossible – particularly to mathematicians, who dislike having 'infinity' in their equations – that many thought some new kind of physics would come to the rescue to prevent the infinite collapse. But it didn't, and by the 1960s it was generally accepted that these mind-bending phenomena really were a possibility. It was around this time that they acquired the name by which we know them now: black holes.

It may seem like a rather big leap to go from the idea of matter being compressed down to an infinitesimally small point to talking about a 'hole' in space – one that it's possible to fall into, but never climb out of. Yet this really is a logical step to take if we think about how gravity works. In the familiar case of Earth, we know that its gravitational pull gets stronger the closer an object is to its surface. That's why the International Space Station, 250 miles above the surface, has to whiz around at a very high speed in order to remain in orbit, completing a revolution in just 90 minutes. However, satellites at the geosynchronous altitude of 22,000 miles can move much more slowly,

The quasar 3C 273 provided the first hints of supermassive black holes

SUPERMASSIVE BLACK HOLES CAN ACCELERATE PARTICLES ALMOST TO LIGHT SPEED

taking a whole day to complete an orbit. There's another speed, around 40 per cent greater than orbital velocity, that's also of interest to spacecraft engineers. Known as 'escape velocity', it's the speed with which an object has to travel in order to break free of Earth's gravitational pull and head into space. And this doesn't only apply to Earth – all other astronomical objects have their own escape velocities. It's a quantity that, like orbital speed, increases the closer you are to the object, as well as increasing in proportion to the object's mass.

If black holes have a reputation for being 'dangerous', we can now see why this is. They have a lot of mass compressed into an infinitesimally tiny volume, which means that if we're not careful we can get very, very close to them. Being at such a short distance from such a massive object means that its escape velocity will be extremely high. In fact, there will be one particular distance at which the escape velocity equals the speed of light. Since nothing can travel faster than this speed, it means that the black hole is surrounded by a sphere of this radius, known as the 'event horizon', within which objects are trapped forever. Nothing can ever escape from inside the event horizon, not even light, and that's why black holes are called 'black'. As to why they're called 'holes'? We can imagine a three-dimensional hole, with a diameter equal to the event horizon, into which an object can fall with no hope of ever getting out again.

When people talk about the size of a black hole, they're almost always referring to the diameter of the event horizon. The thing that actually creates the black hole, the enormous concentration of mass at its centre that's sometimes called the 'singularity', actually has no size. But that's really only a technicality because you

Did you know?

The discoverers of Sgr A* won a Nobel Prize for it

The Event Horizon Telescope's first image of Sgr A*, released in 2022

TYPES OF BLACK HOLE

STELLAR-MASS BLACK HOLE

1 SOLAR MASS
RANGE: 5 to 100

These are classic black holes as they were originally theorised, resulting from the gravitational collapse of very massive stars at the end of their lives. There may be millions of these in the Milky Way alone, though they're usually only detectable when part of a binary system.

INTERMEDIATE-MASS BLACK HOLE

2 SOLAR MASS
RANGE: 100 to 10,000

Scientists believe that black holes in this mass range should exist, formed as a result of the merger of two or more stellar-mass black holes. Little is known about them because they're difficult to detect, but around 300 candidates have been observed.

SUPERMASSIVE BLACK HOLE

3 SOLAR MASS
RANGE: 10,000 to 1,000,000,000+

It's now known that the majority of galaxies have a single black hole of this type at or near their centres. These probably formed very early in the history of the universe and have subsequently grown in size by accreting surrounding stars and other objects.

SUPERMASSIVE COMPARISON

A look at some of the largest supermassive black holes that have been discovered so far

5 3C 273
Mass: **0.9 billion solar masses**
Distance from Earth: **2.4 billion light years**
The first quasar ever discovered, this is still the brightest one visible in our skies, bright enough to be seen even with a simple telescope, making it the most distant object observable by amateur astronomers.

4 CYGNUS A
Mass: **1 billion solar masses**
Distance from Earth: **760 million light years**
This galaxy is one of the strongest radio sources in the sky. As such, it was first observed by the earliest radio telescopes as far back as 1939, long before its true nature was understood.

3 MESSIER 87
Mass: **7 billion solar masses**
Distance from Earth: **53 million light years**
This supergiant elliptical galaxy is the largest member of the Virgo Cluster. Its central black hole made headlines in 2019 as the first black hole to be imaged by the Event Horizon Telescope.

WHEN BLACK HOLES PULL STARS APART, IT'S CALLED SPAGHETTIFICATION

DO YOU KNOW? ...they're talking about its mass, not its physical...

1,500 LIGHT YEARS

Distance to the closest known black hole, Gaia BH1

1 TON 618

Mass: **40 billion solar masses**
Distance from Earth: **18.2 billion light years**
Tonantzintla 618, to give it its full name, is one of the most distant known quasars. Blasting out 40 decillion megawatts, or 140 trillion times as much power as the Sun, it's one of the brightest objects in the universe.

11 SOLAR SYSTEMS WIDE

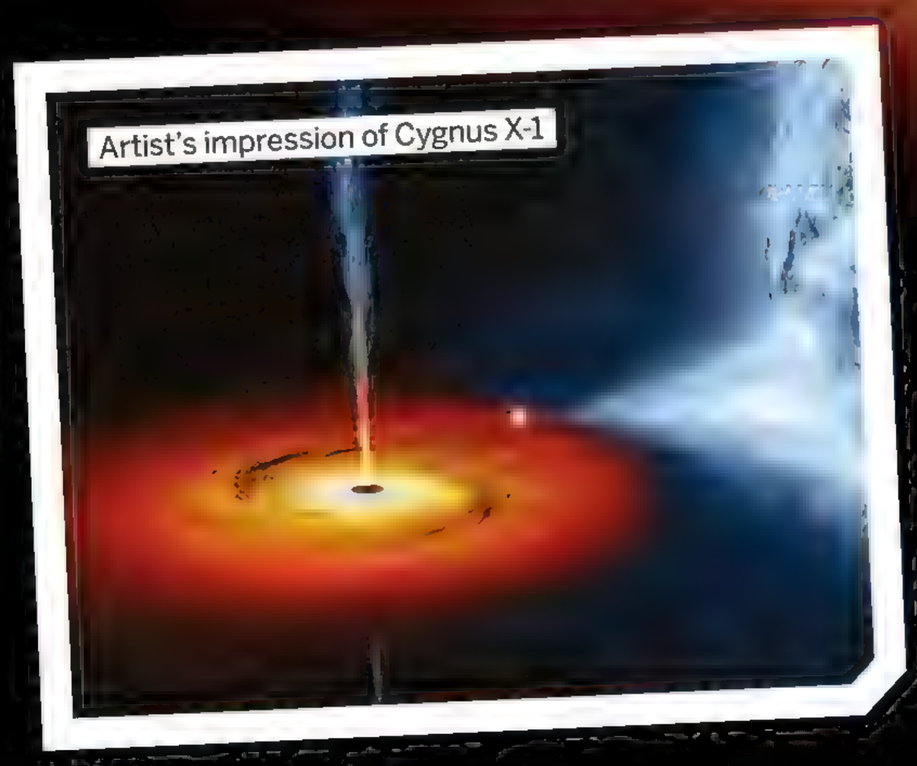
2 OJ 287

Mass: **18 billion solar masses**
Distance from Earth: **3.5 billion light years**
This is another type of active galaxy, related to a quasar but more highly variable, called a BL Lacertae object. It actually contains two supermassive black holes, the second one a 'mere' 150 million times the mass of the Sun.

MILKY WAY MONSTER

The Milky Way is fairly typical of the spiral galaxies we see in the universe around us. One characteristic shared by most galaxies is that the density of stars and other matter rises steeply towards the centre. This means there's always going to be a huge mass concentrated right in the centre, but it can be difficult to establish if this is a black hole or simply a very dense conglomeration of stars. The presence of a strong radio source, called Sagittarius A* or Sgr A*, right at the centre of the Milky Way implied there probably was a black hole there, but its existence was only clinched when astronomers noticed stars in that region orbiting around an invisible object at a third the speed of light.

Sgr A* is around 4,000,000 solar masses, with an event horizon 16,000,000 miles across

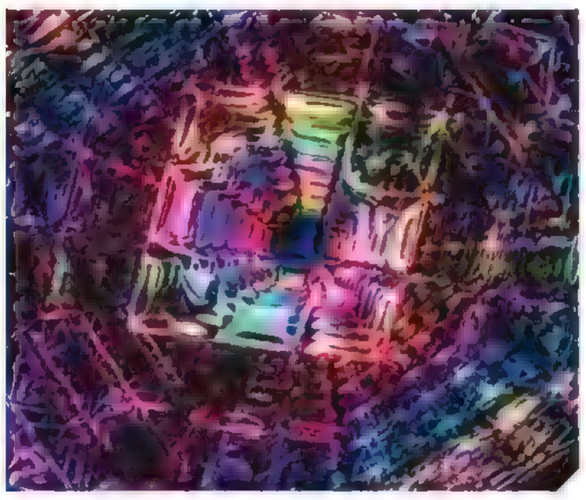

Artist's impression of Cygnus X-1

150+

There are plenty of confirmed supermassive black holes with direct mass measurements

THE SMALLEST BLACK HOLES

Although no one has ever found one, it's possible that very low-mass black holes exist in the universe. According to standard theories of cosmology, black holes of almost any mass might have been created in the first second after the Big Bang. Referred to as 'primordial black holes', the very smallest of these would have been unable to survive to the present day, but those above a trillion kilograms or so may well have done. This is roughly the mass of a typical asteroid, or of a mountain on Earth, yet a black hole of that mass would have an event horizon smaller than the size of a proton – the subatomic particle found in the nuclei of atoms. This is small enough that it would be subject to quantum-mechanical effects, and black holes of this size are sometimes referred to as 'quantum black holes'.



Artist's impression of a microscopically small quantum black hole

Most supermassive black holes are surrounded by 'accretion discs' of swirling gas, as imagined here

can never get anywhere near it. Even the event horizon itself isn't a particularly large thing when compared to any ordinary object containing the same amount of mass. We can see this by trying to imagine what an escape velocity equal to the speed of light means. NASA's Parker Solar Probe is currently orbiting about three solar diameters above the Sun's surface at a speed approaching half a million miles per hour – and its escape velocity would be almost 50 percent faster than that. But even this is only around a thousandth of the speed of light.

It turns out that for a hypothetical black hole with the same mass as the Sun, the event horizon would be less than four miles across. If you were unlucky enough to be orbiting it at that distance, you'd have the entire mass of the Sun pulling you down into that small volume of space, and you'd have to travel faster than light if you wanted to escape from it.

Up to this point, everything we've said about black holes has been purely theoretical. It's a well-established theory that gives us strong reasons for believing that black holes can indeed exist... but if they do, how are we ever going to see them? After all, one of their defining characteristics is that no light, or any other form of radiation, can escape from them. Fortunately, though, there are a couple of ways in which a black hole can be detected, even if we can't see it directly. One is by its gravitational effect on nearby stars, which will orbit around the black hole in a way that gives its presence away. Secondly, there's the black hole's effect on any gas and dust in its vicinity – while they won't be instantly sucked into it in the manner of a Hollywood movie, they will swirl around it at high speed, becoming heated up to a very high temperature in the process. This superhot material then emits X-rays and other high-energy radiation, which can be detected using suitable instruments. It was in this latter way that the first serious black hole suspect, Cygnus X-1, was discovered in 1965. Years later, after a lot more data had been collected, it was confirmed to be one.

With a mass ten or more times that of the Sun and an event horizon around 50 miles across, Cygnus X-1 was a perfect match to theoretical predictions of what a black hole might look like if it was formed from the collapse of a high-mass star. But back in 1963, even before Cygnus X-1 was discovered, astronomers found a much more distant object, 3C 273, that they couldn't explain at all. This turned out to be a quasar – a type of galaxy with an unimaginably powerful source of energy at its centre. After many years of study, it was eventually realised that this too had to be a black hole – but one of incredible size. It wasn't merely ten times the mass of the Sun, it was getting on for a billion times its mass. Astronomers had discovered a supermassive black hole.

Quasars are one of several types of active galaxy, all of which blast out so much energy from their central regions that astronomers have known for some time that they must harbour giant black holes in order to power them. A more recent discovery, however, is that even an ordinary galaxy can have a large central black hole. In these cases there isn't enough material falling into the black hole to generate the kind of radiation we see from active galaxies. Instead, that other method of detecting black holes comes into play, by observing the motion of stars orbiting around the black hole. By observing stars in the centres of 'normal' galaxies, super-powerful telescopes like Hubble and the James Webb Space Telescope can show that there must be supermassive black holes there too.

24 LIGHT YEARS

A relatively small distance separates two supermassive black holes in the galaxy B2 0402+379

Did you know?

THE EHT'S GLOBAL NETWORK

Telescopes around the world working together

1 Atacama Desert, Chile 2 Pico de Valeta, Spain
3 Mauna Kea, Hawaii 4 Sierra Negra, Mexico
5 Mount Graham, Arizona 6 South Pole Station

SUPERMASSIVE MYTHS BUSTED

We bust some common misconceptions about these monstrous celestial objects

1 THEY'RE INSATIABLE EATERS

Black holes only swallow stars and other objects that get close enough to be pulled in by gravity; they don't go out of their way to find material to 'eat'. Plenty of stars happily orbit close to the black hole for millions of years without getting swallowed up.

2 THEY ARE INVISIBLE

While no light emerges from inside the black hole itself, they're far from invisible. Just outside the event horizon, there's often a disc of super-heated gas that can be a strong source of electromagnetic radiation. In fact, some black holes are among the brightest objects in the universe.

3 THEY'RE HUGE

This myth comes from misinterpreting the term 'supermassive', which refers to a black hole's mass rather than its size. In fact, black holes are very compact in size – much more so than any ordinary object, such as a dense star cluster, having the same mass.

4 THEY WILL SUCK EVERYTHING IN

This is probably the most prevalent myth of all, and is completely false. Black holes only interact with other matter through their gravitational pull, which until you get close to the event horizon works in exactly the same way as the gravity of any other object of the same mass.

5 THEY ARE SPACE-TIME PORTALS

This myth has become popular through its appearance in numerous science-fiction movies. It's true that some scientists have proposed something like this in the past, but these are fringe theories for which there's no observational evidence, and thus they aren't widely accepted.

6 THEY CRUSH INFALLING OBJECTS

Paradoxically, falling objects don't feel the force of gravity, even the huge gravity of a black hole. But if you fell in feet first, the force on your feet would be much stronger than on your head – rather than being crushed, you'd be stretched and pulled apart.

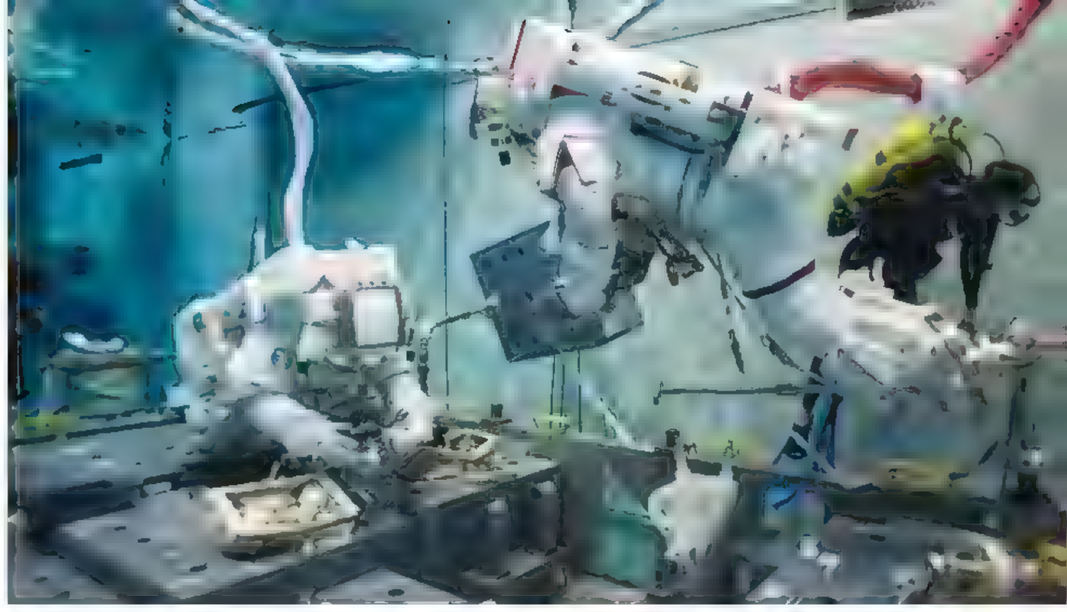
60,000 ROTATIONS PER MINUTE

Black hole GRS 1915+105 spins on its axis at a terrific speed

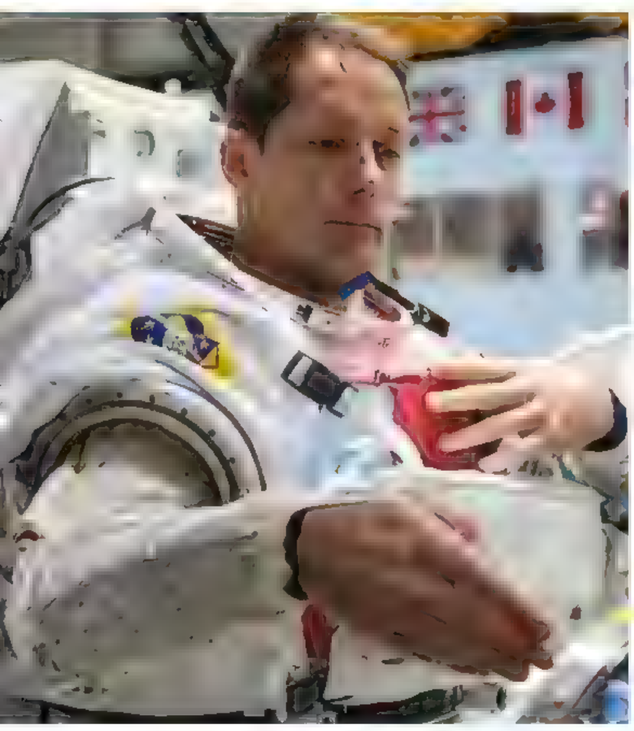
THE EVENT HORIZON TELESCOPE

These days, it's not too difficult for astronomers to establish the existence of a supermassive black hole by observing its effects on the stars and other material surrounding it. But obtaining a direct image of a black hole is another matter. The biggest problem relates to what astronomers call 'angular resolution' – the ability of a telescope to see physically small objects a long way away. An example would be trying to image an orange on the surface of the Moon. It turns out that even the 'easiest' supermassive black holes – such as Sgr A* in our own galaxy or the giant one in Messier 87 – are about that level of difficulty. In order to take pictures of them, astronomers have to employ not just a single radio telescope, but a whole network of them all over the planet. This network is called the Event Horizon Telescope, or EHT.

The EHT's view of Messier 87's black hole, seen in polarised light



HOW ASTRONAUTS TRAIN FOR SPACE



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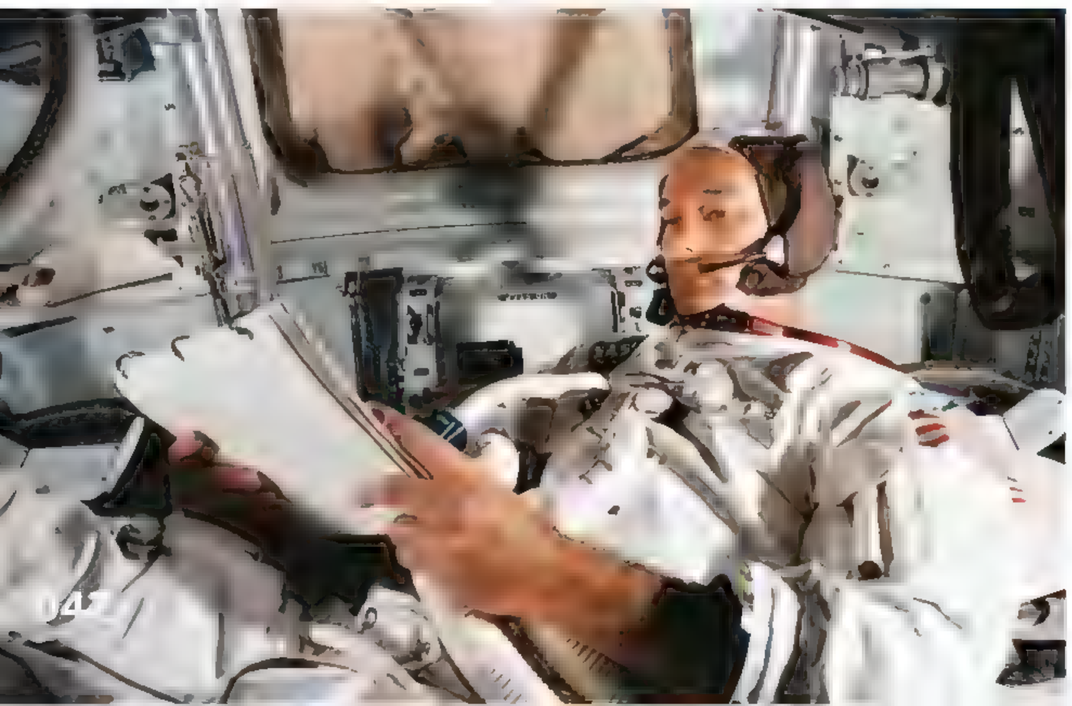
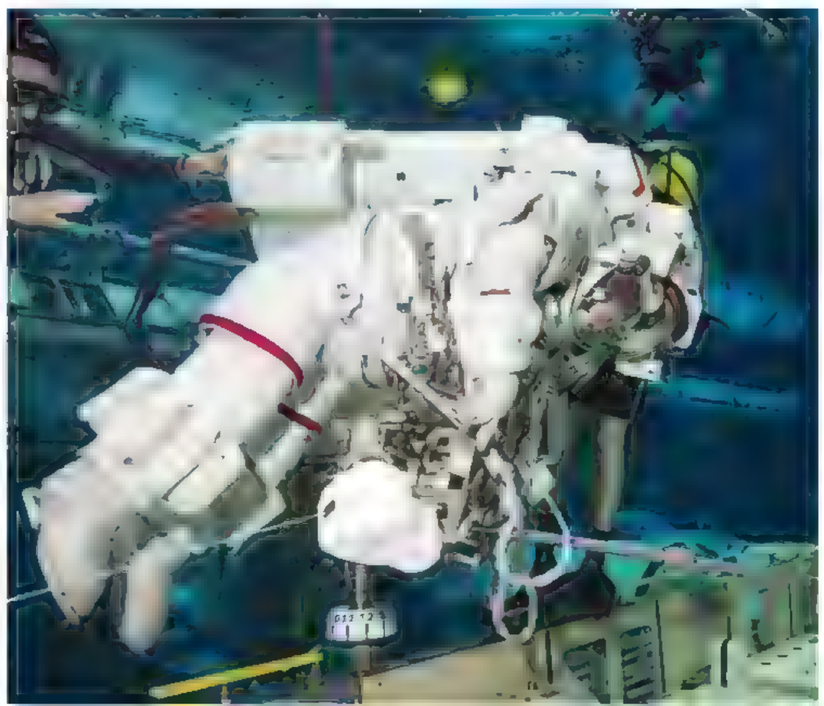




DID YOU KNOW? In space, astronauts lose an average of 1.0 to 1.5 per cent of mineral density in weight-bearing bones per month

To build up their bodies, cope with confinement and monitor machinery, astronauts must embark on rigorous training programs

For many, it's the dream career and ultimate adventure to travel hundreds of miles away from our planet and live in space. The view of Earth from orbit is something a very small minority get to experience, and for working astronauts, this prize comes with long-term dedication and commitment. Astronauts need to have extensive skills, including a scientific brain to perform experiments, physical strength and coordination to maintain a healthy body in extreme conditions and the mental hardiness to float in confined and overcrowded spaces, far from not just close family, but the entire planet. With so much of space being unexplored, astronauts need to be prepared to work under intense pressure and navigate unfamiliar environments and situations.

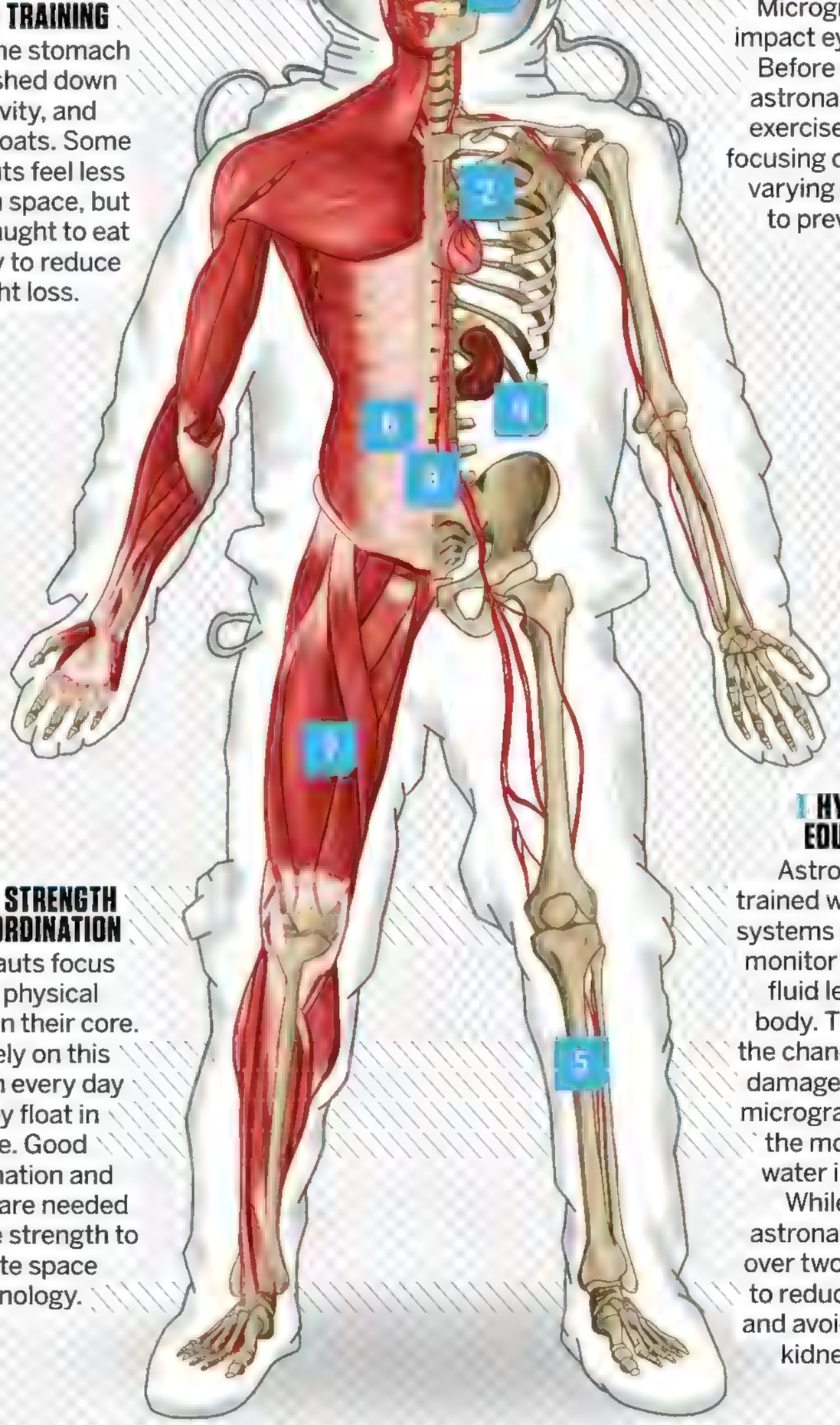
For most space missions, the types of astronauts required are pilots, mission specialists and payload specialists. A pilot's first true attempt at spaceflight occurs on the date of the mission, but thanks to advanced technology they can practise with realistic simulations. These simulations can be programmed to display unique situations, testing the astronaut's critical thinking and adaptability to new scenarios. Astronauts usually spend 300 hours in simulators before going on a mission.

Mission specialists are trained for life in space, but their training focuses less on controlling spacecraft. Instead, these astronauts carry out practical roles such as medicine or engineering, and often run spacecraft maintenance checks. Payload specialists are much rarer and can be sent to space if there is a specific experiment that requires knowledge most astronauts aren't trained in. These astronauts don't follow the same selection process as the majority, but need to demonstrate many of the same skills. Before any selected astronaut departs Earth to experience life in space, they usually complete at least two years of astronaut training.

Did you know?
Astronauts stay hydrated with recycled water

PHYSICAL TRAINING

How do astronauts prepare their bodies for the conditions of space?



1 MENTAL PREPARATION
Candidates' mental health is considered when recruiting. After recruitment, they undergo training in isolated and challenging environments to build mental strength.

2 CARDIOVASCULAR TRAINING
Astronauts perform regular aerobic exercises as part of training to keep their hearts healthy. With less gravity in space, they need strong hearts to keep blood pumping effectively.

3 EYE FOCUS
Microgravity can impact eye strength. Before missions, astronauts do eye exercises, such as focusing on objects at varying distances, to prevent this.

4 HYDRATION EDUCATION
Astronauts are trained with hydration systems about how to monitor and balance fluid levels in the body. This reduces the chances of kidney damage in space, as microgravity impacts the movement of water in the body. While in orbit, astronauts exercise over two hours a day to reduce salt levels and avoid developing kidney stones.

5 BONE-BUILDING
To prevent bone loss, astronauts carry out multi-joint weight-bearing exercises before, during and after space travel.

6 FOOD TRAINING
Food in the stomach isn't pushed down by gravity, and instead floats. Some astronauts feel less hungry in space, but they're taught to eat regularly to reduce weight loss.

7 GENE SHIELDING
Astronauts learn how to monitor radiation exposure levels. This is essential, as radiation can cause genetic changes. Overall fitness training potentially benefits genetic stability.

8 CORE STRENGTH AND COORDINATION
Astronauts focus much physical training on their core. They rely on this strength every day as they float in space. Good coordination and balance are needed alongside strength to operate space technology.

NASA'S UNDERWATER TRAINING BASE

Aquarius is an undersea research station where astronauts live for up to three weeks at a time to endure NASA Extreme Environment Mission Operations (NEEMO)

1 DESCENT
The Reef Base off Key Largo in Florida, lies 19 metres underwater but is built to withstand the pressure of depths over 36 metres.

2 METAL HOME
The steel habitat measures 13 by 6 by 5 metres and is divided into three sections.

3 WET PORCH
Astronauts enter here where the air pressure is kept the same as the water pressure. This stops water from flooding in between missions.

4 ENTRY LOCK
Between entering the living area and the wet porch, astronauts wait in this compartment while the air pressure is matched to the environment they are about to enter.

5 MAIN LOCK
The main compartment is at normal atmospheric pressure.

American astronaut Mark Vande Hei running on a treadmill on the International Space Station

FITNESS IN SPACE

Physical training doesn't stop as soon as astronauts make it to space. Usually, they have strict exercise regimes that keep their bodies fit and strong. This is especially important when certain muscles are used less in microgravity, such as core leg muscles that no longer support the body's weight. Space gyms are designed to provide a similar sensation to gravity. For example, on a treadmill bungees are attached to the runner to pull their weight down onto the conveyor belt. Other exercise facilities include a pedalling machine in which the astronaut is harnessed in place and a weightlifting device called the Advanced Resistive Exercise Device (ARED). This consists of vacuum cylinders that each contain a piston with a vacuum on one side and air on the other. Air is drawn out of the cylinder when an astronaut pushes the bar, and the vacuum resists the movement. This resistance, which microgravity doesn't naturally provide, keeps astronauts' muscles and bones strong.

DID YOU KNOW? Scientists that stay in the Aquarius Reef Base for 24 hours or more at a time are known as 'aquanauts'

6 SLEEPING AREA
There are six beds in the sleeping area, with three bunks on each side. This trains astronauts to live in tight quarters.

7 WATERWALKS
Astronauts embark on daily waterwalks outside the habitat to emulate spacewalking in low gravity. During these missions they test communication skills, use underwater versions of space rovers and learn to monitor their own oxygen levels.

8 STORAGE
In the storage cupboards are food rations containing dehydrated foods astronauts would eat on a space mission.

9 SCIENCE LABORATORY
Some missions include in-habitat experiments, which can be carried out here.

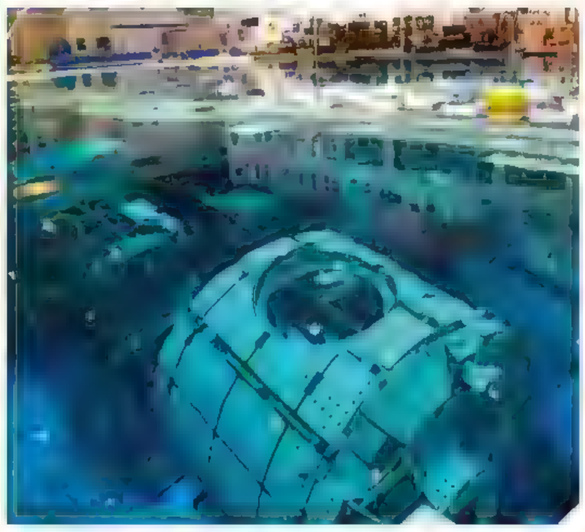
10 WINDOW
Through this small porthole astronauts can see ocean life outside.

Did you know?
The NBL is kept between 27 and 30 degrees Celsius.

POOL PREPARATION

Being submerged underwater and entering a near-vacuum may at first seem like completely different experiences, but much of an astronaut's training takes place in a pool. NASA's Neutral Buoyancy Laboratory (NBL) is located at the Sonny Carter Training Facility in Texas and is one of the largest indoor pools in the world, with enough water in it to fill nine Olympic-sized swimming pools. By wearing spacesuits, breathing apparatus and a buoyancy control device, which is a flotation device with an inflatable bladder, astronauts can spend numerous hours at a time beneath the water.

Astronauts control the buoyancy device by pressing a button to inflate and deflate the bladder with air. When they stop sinking or rising in the water, they have reached neutral buoyancy. This is similar to the feeling of weightlessness experienced in space. Multiple mock-ups of the outside of parts of the International Space Station can fit in the pool at one time, as the pool covers an area of 61.5 by 31.1 metres, with a depth of 12.2 metres. Teams work to communicate, move in their suits without bearing their full weight and keep track of their personal oxygen usage.



A full-size mock-up of the International Space Station's modules can be seen under the pool's surface

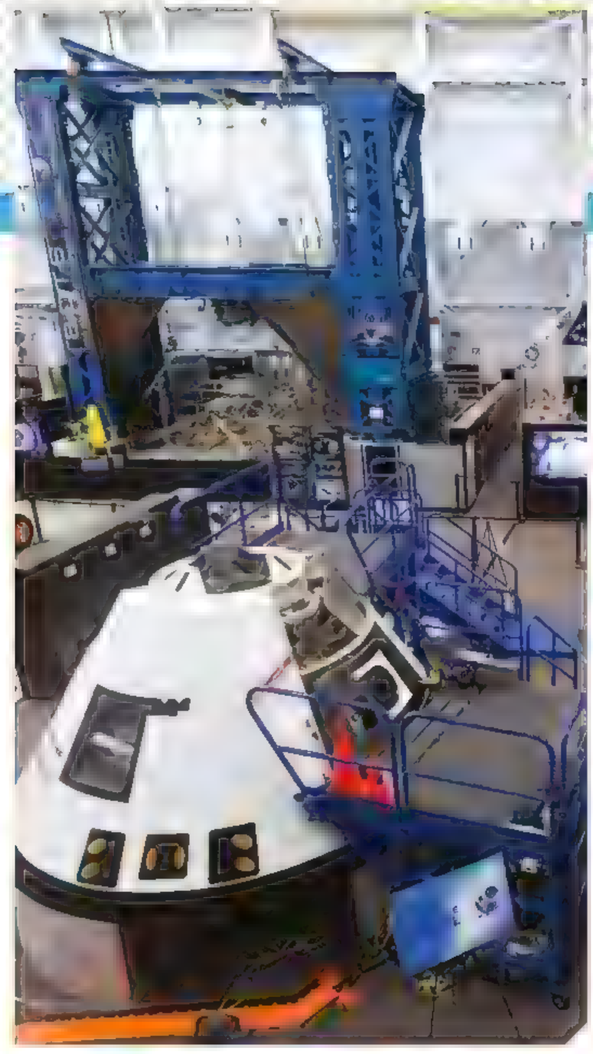
SPACE SIMULATION LOCATIONS AROUND THE WORLD

EUROPEAN SPACE AGENCY CAVES, ITALY
The Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills course takes place in the caves of Sardinia. The lava rock underground voyage involves carrying out scientific activity, cave mapping and [illegible]

LUNARES, POLAND
This research base in Poland is a place for astronauts to carry out Mars simulation [illegible]

HI-SEAS, HAWAII
[illegible] above sea level on the slopes of Mauna Loa. The location is used to simulate Mars and Moon missions. NASA missions have last between 8 and 12 months. The habitat, communication systems and natural geology all match those of a future exploration mission.

DEVON, CANADA
The Flashline Mars Arctic Research Station in Canada is a [illegible] where astronauts can train for Mars-specific missions. Astronauts stay at the facility for [illegible] The surrounding geology simulates the Martian environment.



The Space Vehicle Mockup Facility spans 42,500 square metres

MANIPULATING MOCK-UPS

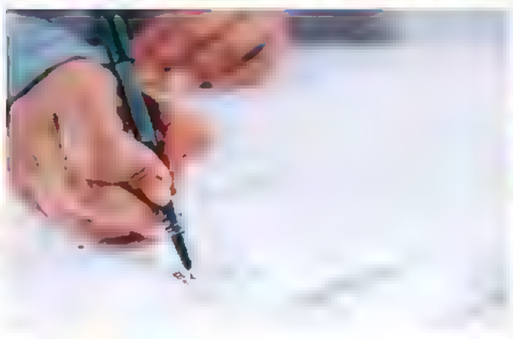
An astronaut needs to be confident in operating their appointed spacecraft and machinery. However, they are limited in how much they can practise on the actual equipment before they go to space for real. This is where exact replicas are essential. At NASA's Space Vehicle Mockup Facility at Johnson Space Center in Houston, Texas, there are identical replicas of the pressurised modules of the International Space Station and spacecraft such as the Orion capsule of the Artemis program.

At this facility, astronauts can experiment with the equipment, practise emergency operations and mix apparatus without compromising the space-going craft. Training in the real spacecraft can be risky and logistically challenging, but with an identical layout, the mock-up helps familiarise them with its functions.

THE ROAD TO SPACE

From school studies to in-space training, how do you become an astronaut?

EDUCATION QUALIFICATIONS
Astronauts are usually required to complete a degree and postgraduate qualification in science, engineering, medicine, aeronautics or mathematics.



TEST PHASES
Selected applicants will undergo a series of tests, including cognitive, motor coordination, personality, group work, practical and technical tests.

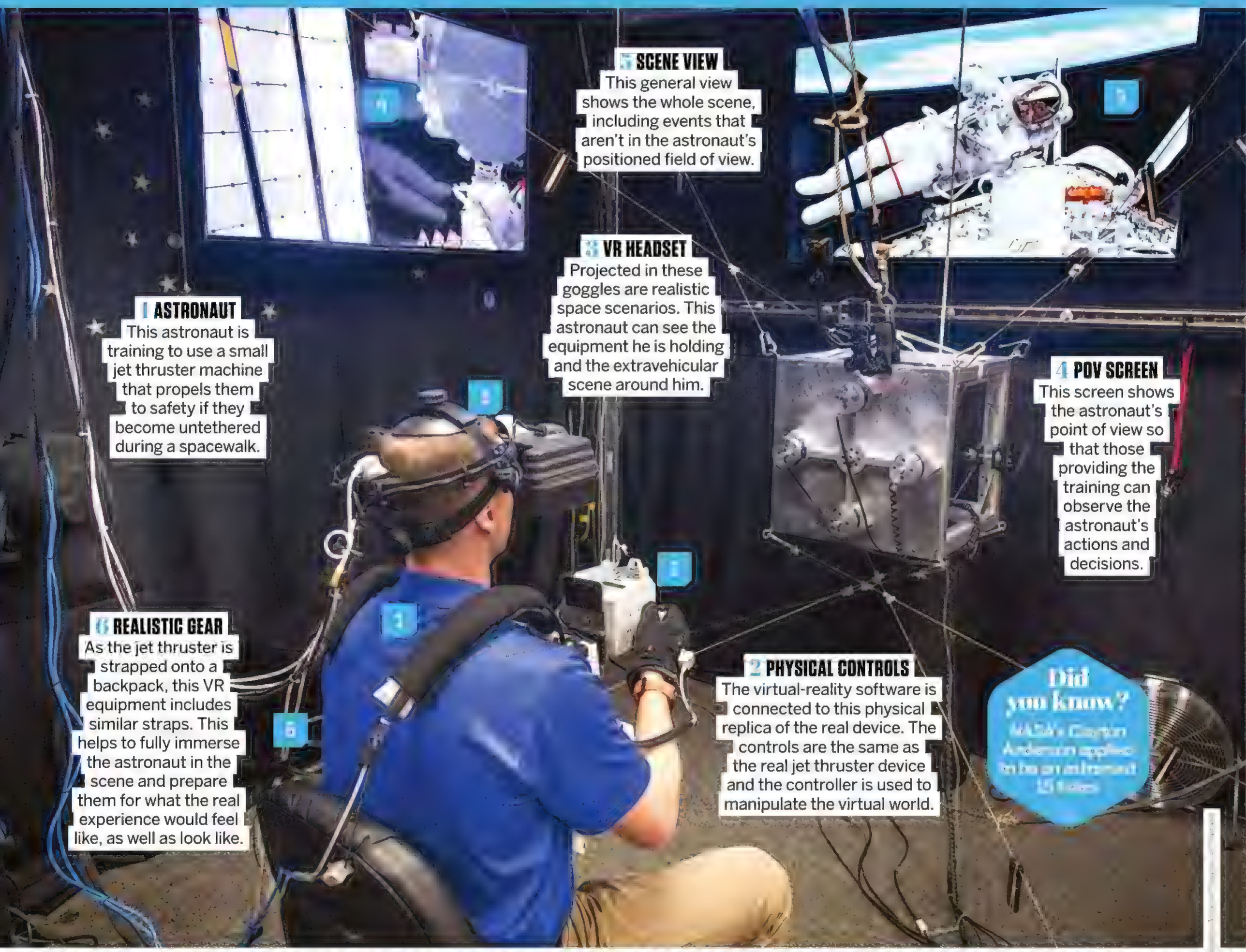
INTERVIEWS
Those whose test results meet the international medical standards for spaceflight are considered for multiple interview stages in front of space agency panels.

SELECTION
A small percentage of qualified applicants will be selected to undergo astronaut training. In 2020, of 12,000 people only 0.083 per cent were successful.

DID YOU KNOW? There is no age limit to apply to be a NASA astronaut

ACCESSING THE VIRTUAL WORLD

Inside NASA's Virtual Reality Training Laboratory



1 ASTRONAUT
This astronaut is training to use a small jet thruster machine that propels them to safety if they become untethered during a spacewalk.

3 VR HEADSET
Projected in these goggles are realistic space scenarios. This astronaut can see the equipment he is holding and the extravehicular scene around him.

5 SCENE VIEW
This general view shows the whole scene, including events that aren't in the astronaut's positioned field of view.

4 POV SCREEN
This screen shows the astronaut's point of view so that those providing the training can observe the astronaut's actions and decisions.

6 REALISTIC GEAR
As the jet thruster is strapped onto a backpack, this VR equipment includes similar straps. This helps to fully immerse the astronaut in the scene and prepare them for what the real experience would feel like, as well as look like.

2 PHYSICAL CONTROLS
The virtual-reality software is connected to this physical replica of the real device. The controls are the same as the real jet thruster device and the controller is used to manipulate the virtual world.

Did you know?
NASA's Captain Anderson spent [illegible] in orbit

BASIC TRAINING

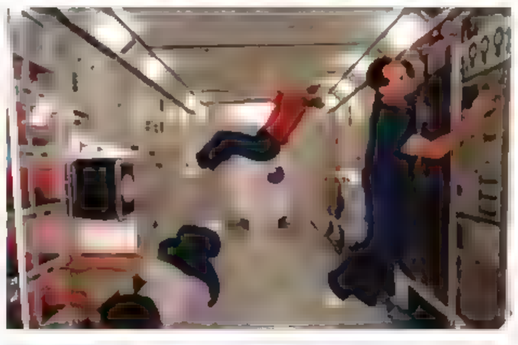
Initial training programs usually include science and engineering fundamentals, an introduction to space vehicles and basic astronaut and survival skills.

SPECIALISED TRAINING

All astronauts that work on the International Space Station begin training on how to operate and maintain the station's modules, equipment and vehicles.

MISSION-SPECIFIC TRAINING

Once assigned to a mission, astronauts are split into smaller groups to study the research equipment and spacecraft elements for their mission.



IN-SPACE TRAINING

Astronauts receive further training to demonstrate their abilities on location. This can involve regular emergency drills and learning new in-space experiments.

HOW EARTH GOT ITS WATER

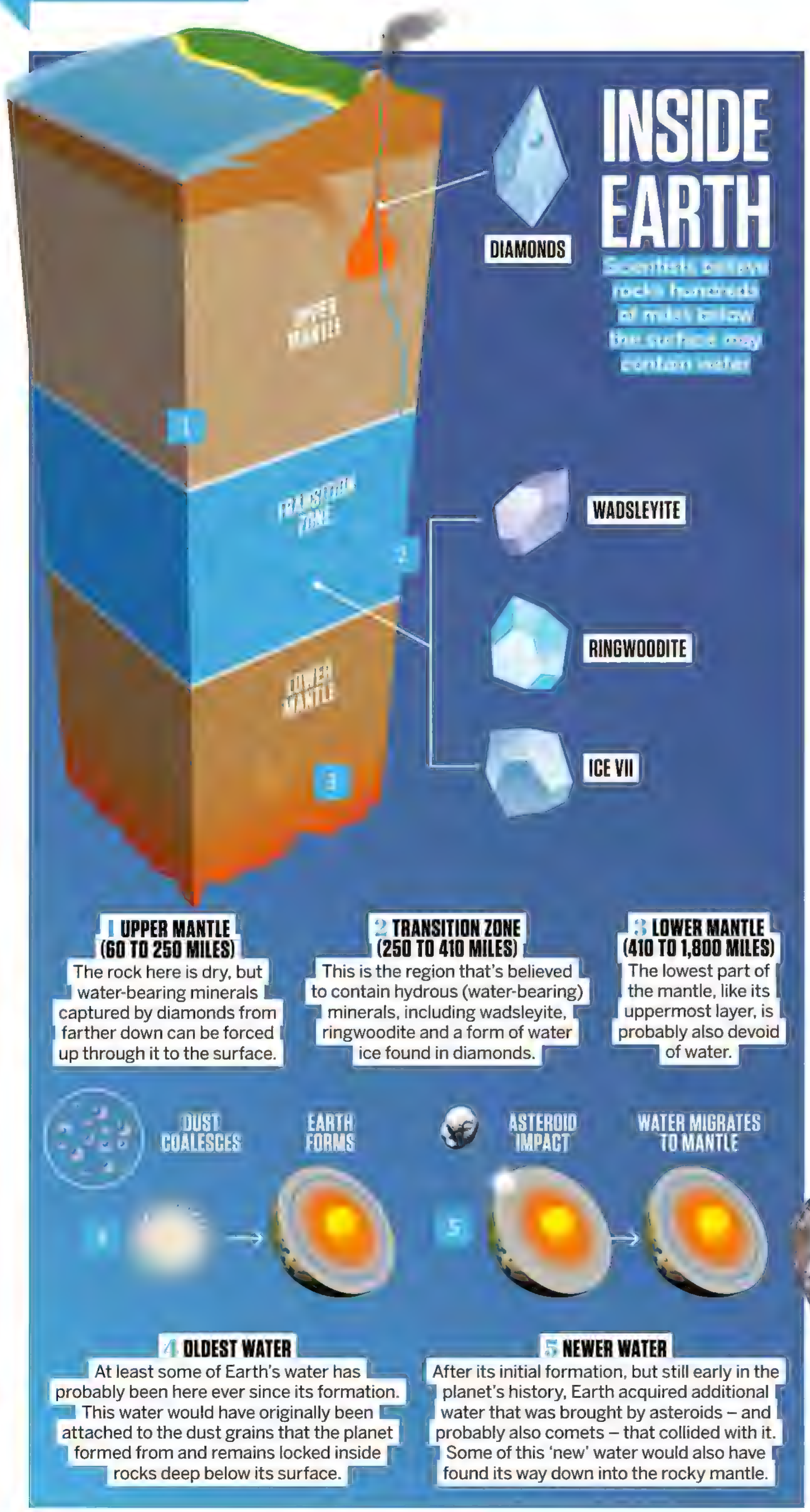
A lot of our water likely came from space, which could be shown by a NASA spacecraft that just returned from a nearby asteroid

ANDREW MAY

It's easy to take water for granted on Earth. It surrounds us all the time – in the sea, in rivers and streams, in rain, in clouds even when it's not raining and in frozen form as snow and ice in winter. But where did all this water come from? In its earliest days, Earth was extremely hot – maybe as high as 2,000 degrees Celsius – so there couldn't have been any liquid water on the surface at that time. In fact, there are several scientific theories as to how our planet got its water.

Earth is often described as a 'water planet', which is a good description of the way it appears from space, with water, in liquid or frozen form, covering three-quarters of its surface. But if you delve a little deeper, it turns out this is only a superficial impression. Most of our planet is solid rock, with water making up just 0.05 per cent of its mass. Ironically, although Earth is the only place in the Solar System where water is easy to see on the surface, it's a long way from being the most water-rich body orbiting the Sun.

In fact, water becomes increasingly prevalent the farther out you look in the Solar System, though due to the cold temperatures, much of it exists frozen as ice. But even liquid water may exist in copious quantities deep in the interior of some bodies,



such as Jupiter's moon Ganymede, where liquid water may make up as much as 46 per cent of its volume. By the time you get to the outermost parts of the Solar System, such as the Kuiper Belt and Oort Cloud, the majority of the material there is in the form of frozen water.

The significance of this for water on Earth is that these outer regions are the very places comets come from. It's likely that, in the distant past, large numbers of comets may have collided with Earth. These collisions would have brought water to our planet, and at one time this was the leading theory to explain the origin of our water. But when scientists looked at cometary water in more detail, they discovered a subtlety that means this can't be the true explanation – at least not for the majority of Earth's water.

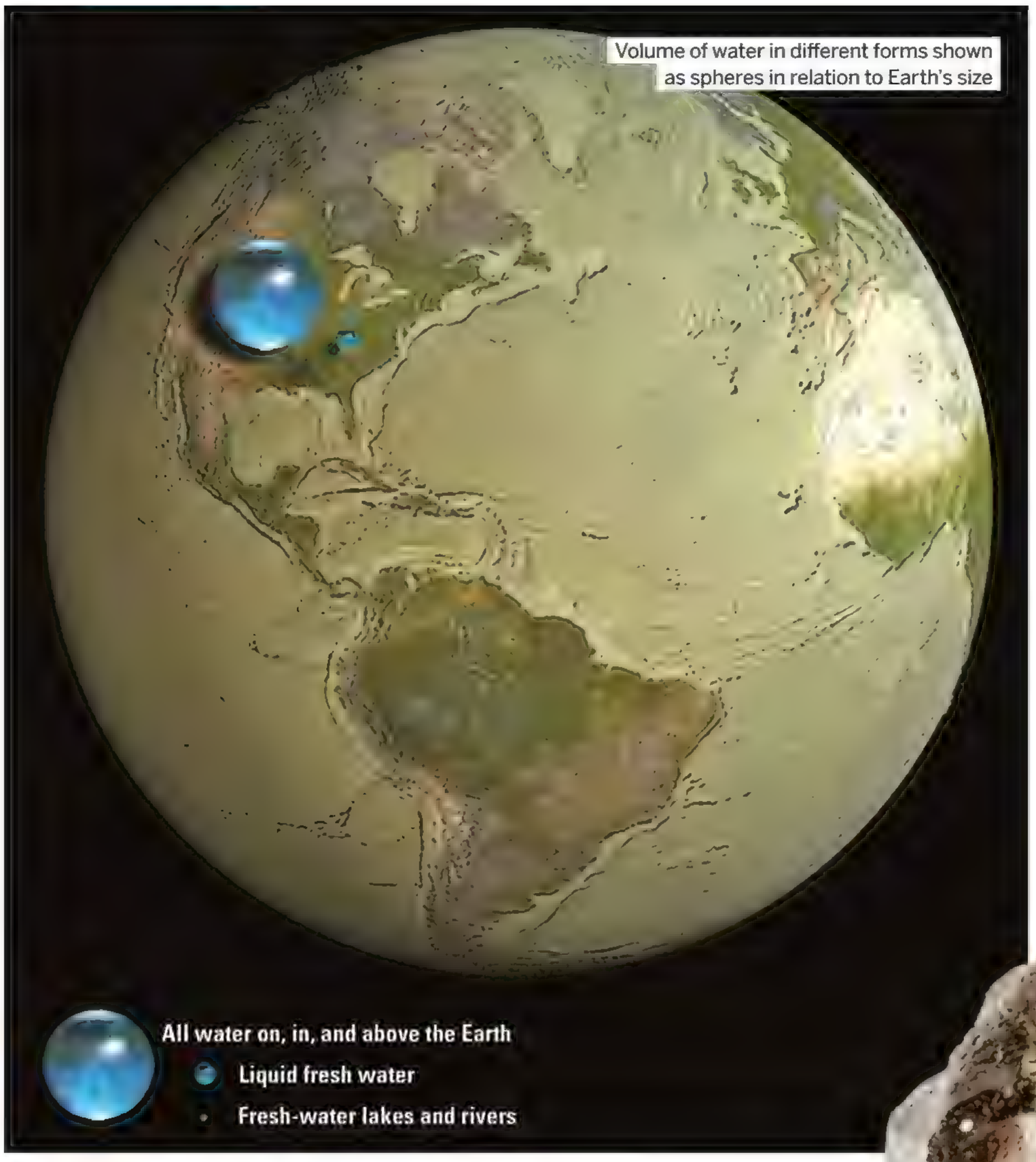
The problem lies with the so-called 'flavour' of water. From a chemical point of view, water is H_2O, made up of molecules containing two

WET METEORITES

The easiest way to test the theory that asteroids brought water to Earth is by studying meteorites. These are pieces of asteroids that entered Earth's atmosphere as meteors and managed to get all the way down to the ground without burning up entirely. From the point of view of chemical composition, there are several different types of meteorite – corresponding to different types of parent asteroid – but the ones of greatest interest in the context of Earth's water are known as carbonaceous chondrites. Within the broad class of carbonaceous chondrites is a particularly rare form known as CI chondrites, of which only nine examples have been found to date. The water in these meteorites is the most ancient ever discovered, dating from the very birth of the Solar System 4.6 billion years ago, yet it makes up as much as 20 per cent of their mass.

Carbonaceous chondrites such as this one have a significant water content

DO YOU KNOW? The largest body of water on Earth is the Pacific Ocean, with an area of 60 million square miles



WATER IS EVERYWHERE

Earth's water exists in some obvious places, like rivers, lakes and oceans, as well as less obvious ones like groundwater in soil. Individual molecules of water don't always stay in the same place, but move around as part of the global water cycle. For example, ocean water may evaporate to form clouds and subsequently fall as rain in some other part of the world. But the overall quantities of water in different forms tend to stay constant. The US Geological Survey has likened these quantities to spheres of different diameters. The total amount of water – including that in the salty oceans – would fill a sphere 860 miles in diameter, while freshwater, including any hidden deep underground, would be 170 miles. Water in lakes and rivers is just 35 miles.

Water-rich diamonds like this, originating in Earth's mantle, indicate the existence of water there

"Cometary water clearly isn't the same flavour as Earth's"

hydrogen atoms and one oxygen atom. But Earth's water contains two different forms of hydrogen: the most common kind, H, having just a solitary proton in the nucleus, and the other – D, for deuterium – containing a neutron as well. The 'flavour' of water refers to the ratio, D to H, of the two types of hydrogen it contains.

Measurements of cometary water clearly show that it isn't the same flavour as Earth's water. In fact, comets vary considerably in their value of D/H, with the best studied comet of all, 67P/Churyumov-Gerasimenko – as visited by the European Space Agency's Rosetta spacecraft in 2014 – having a particularly high D/H ratio, more than three times that of Earth's oceans. On the other hand, there's another family of Solar System bodies that have D/H values much closer to Earth.

At the end of February 2021, a 320-gram chunk of space rock thudded down onto a driveway in Winchcombe, Gloucestershire. Within 12 hours it had been carefully collected and hermetically sealed by scientists, making it one of the most pristine meteorite samples ever obtained. It's also one of the most important clues we have as to the source of water on Earth. Before it broke up in the atmosphere, the Winchcombe meteorite formed part of an asteroid, and it's believed to be a typical example of a large class of such asteroids that orbit the Sun inside the orbit of Jupiter. Analysis of the meteorite revealed it to contain around 11 per cent water by weight, most of this locked up in minerals. Most important of all, its D/H ratio matched that of Earth's oceans almost

Did you know?

Illustration of Earth's water cycle, showing how it's constantly 'recycled' from one form to another

perfectly. Since meteorite impacts would have been much more frequent in the distant past, when the density of asteroids in the space around Earth was higher, this is a strong indication that incoming asteroids were a major contributor to Earth's water.

Part of the asteroid sample collected by Hayabusa2 in 2019

Further support for this idea came in September 2022 following the analysis of a small sample of material collected from the asteroid Ryugu by the Japanese Aerospace Exploration Agency's Hayabusa2 probe. To the surprise of scientists around the world, the sample contained not just water molecules locked up in minerals, but an actual droplet of pure liquid water. In the case of a meteorite this might have been dismissed as earthly contamination, but that wasn't possible here because the sample was collected in the vacuum of space. As exciting as that discovery was, it may soon be overshadowed following the return of a much larger asteroid sample by NASA's OSIRIS-REx mission in September 2023.

As enticing as the idea of water from asteroids is, it may not be the complete answer to the origin of Earth's water. Just as asteroids have water locked up inside the minerals they're made up of, the same may be true of some of Earth's own rocks as well. Indeed, there's evidence that 'primordial water' of this kind can be found hundreds of miles below the surface of Earth. Although this is much too deep to study directly, diamonds that formed at such depths can occasionally be forced up to the surface by volcanic action, and some of these have been found to have a high water content.


Scientists from NASA and Arizona University inspecting the sample-return capsule after its landing

96.5%
Most of Earth's surface water is in the oceans

4.6%
A fraction of meteorites are carbonaceous chondrites

23
Around two dozen planets and moons in the Solar System are known to have water

2019
The year of the first detection of water vapour in an exoplanet's atmosphere

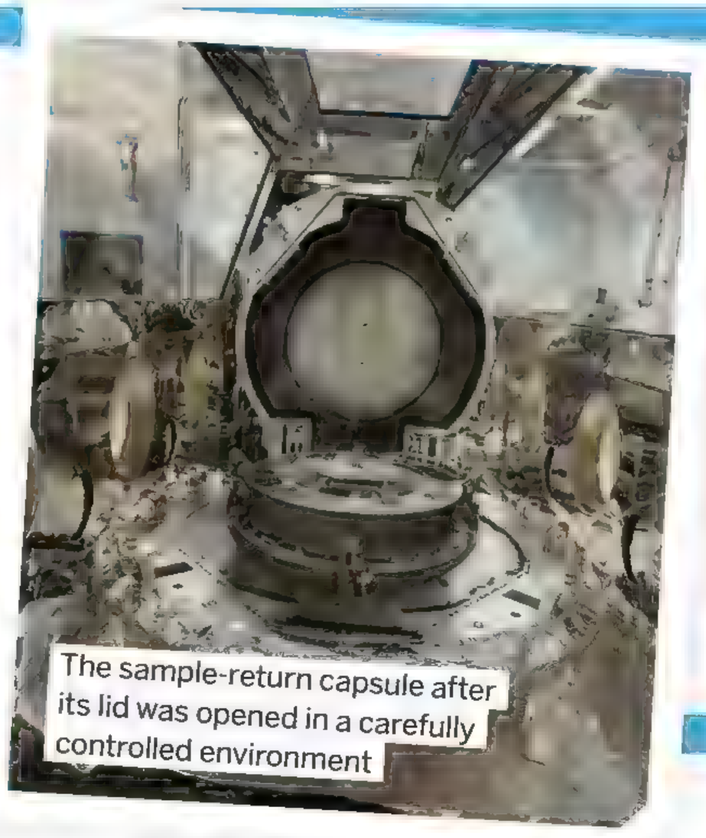
0.007%
Less than one-ten thousandth of Earth's water is accessible for human consumption

2.5 CENTIMETRES
An average of an inch of rain would fall if atmospheric water vapour suddenly condensed

SIX GRAMS
The total weight of asteroid samples collected by Japan's Hayabusa probes

SAMPLES FROM AN ASTEROID

Before OSIRIS-REx collected its sample from the asteroid Bennu, it carried out a survey of the asteroid to help scientists choose the best landing spot. They shortlisted several possibilities, with the one eventually selected being located close to Bennu's north pole; this was chosen because it contained the largest quantity of unobstructed fine-grained material. After a few hundred grams of this material was collected, it was carefully stowed inside the sample-return canister until its arrival back on Earth three years later. It will be a while before NASA fully extracts the canister's contents and distributes it for analysis. However, long before they looked inside the return vehicle three days after its landing, scientists found tiny 'samples' from Bennu in a place they weren't expecting them in the form of a dark, powdery deposit scattered all over the vehicle's avionics deck. Preliminary analysis of this material revealed the abundant presence of water-bearing clay minerals.


The sample-return capsule after its lid was opened in a carefully controlled environment

DO YOU KNOW? The rings of Saturn are made up of particles of 99.9 per cent pure water ice

THE SAMPLE-RETURN CAPSULE

The small vessel, 81 centimetres in diameter, came back down to Earth in September 2023

1 HEATSHIELD
Made from lightweight phenolic-impregnated carbon ablator (PICA), this protected the capsule's delicate contents from the heat of re-entry.

3 SAMPLE CANISTER
Made from aluminium and securely nestled between the heatshield and backshell, this is where the asteroid sample was kept.

2 BACKSHELL
Experiencing less heat because it formed the rear of the descending capsule, this is made from a thinner material called SLA-561V.

5 PARACHUTE
Deployed five minutes before touchdown, this slowed the capsule down from hypersonic speed to a mere 11 miles per hour.

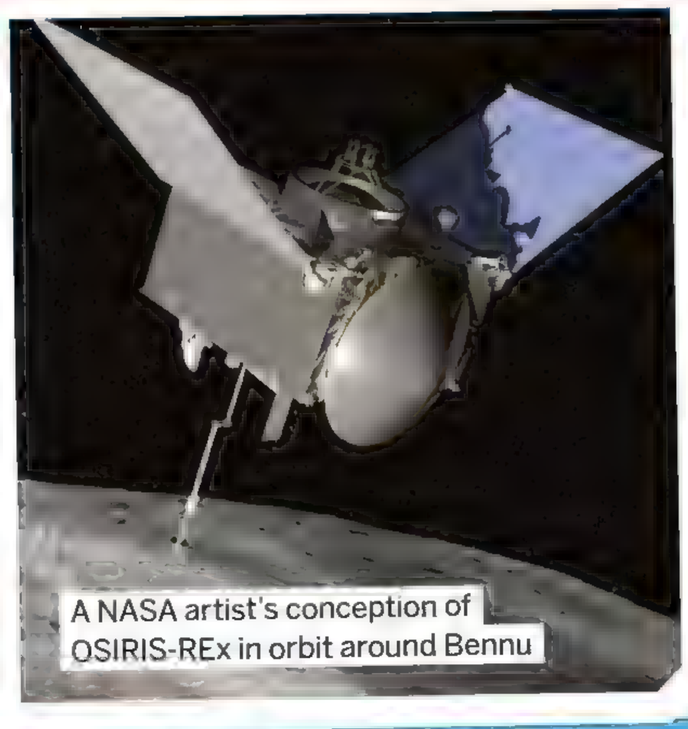
1 AVIONICS DECK
This housed all the capsule's electronic systems, containing everything it needed for communication, navigation and control.

A view of Bennu from OSIRIS-REx

Did you know?
Asteroid Bennu is about 500 metres across

THE OSIRIS-REX SAMPLE-RETURN MISSION

NASA's OSIRIS-REx made headlines when its sample-return capsule landed in the Utah desert containing fragments of rock collected from Bennu. This wasn't the first time that samples from an asteroid had been returned to Earth – the Japanese space agency had already achieved that with its two Hayabusa missions – but NASA's sample is larger and provides more scope for scientific analysis of the asteroid's make-up, including any water it may contain. The spacecraft was launched in September 2016 and arrived at Bennu in December 2018, after which it studied it for almost two years before collecting its rock sample in October 2020. Although it takes its name from an ancient Egyptian deity, it's also an acronym describing the spacecraft's scientific aims: the Origins, Spectral Interpretation, Resource Identification and Security Regolith Explorer. It's now embarked on a second mission, as OSIRIS-APEX – for Apophis Explorer – to another asteroid named Apophis.



A NASA artist's conception of OSIRIS-REx in orbit around Bennu

SUPER SPACEX ROCKET ENGINE

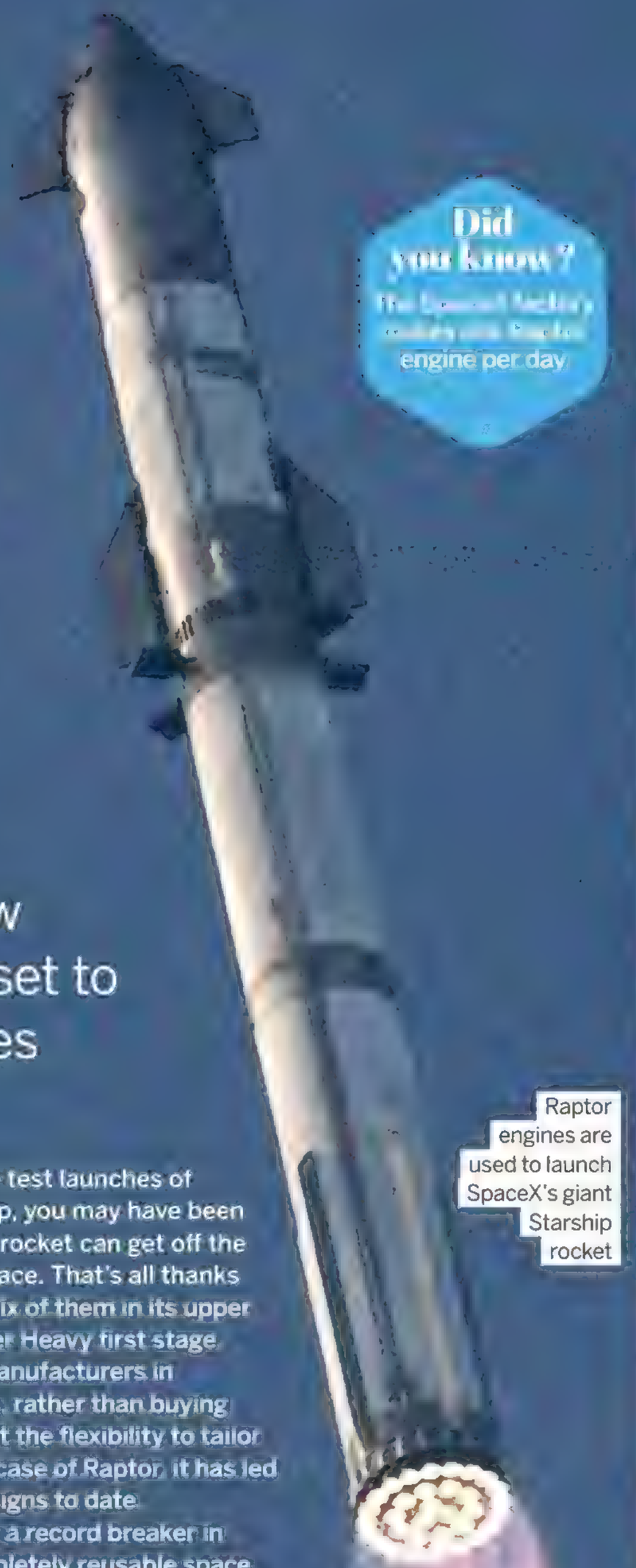
This revolutionary new propulsion system is set to change space launches

ANDREW MAY

If you've ever watched one of the test launches of SpaceX's 120-metre-tall Starship, you may have been amazed that such an enormous rocket can get off the ground, let alone reach outer space. That's all thanks to its specially designed Raptor engines – six of them in its upper stage and an unprecedented 33 in the Super Heavy first stage. SpaceX is unusual among launch vehicle manufacturers in designing and constructing its own engines, rather than buying them from another supplier. But this gives it the flexibility to tailor the engines to its exact needs – and in the case of Raptor, it has led to one of the most revolutionary rocket designs to date.

Apart from its sheer size, Starship will be a record breaker in another way: it will be the world's first completely reusable space launch system. That's in contrast to earlier designs such as NASA's Space Shuttle and SpaceX's own Falcon 9 rocket, which were only partially reusable. It's this goal of complete reusability that's driven the radically new design of the Raptor engine. It's powered by methane – an unusual choice for rocket fuel, but one that reduces soot buildup inside the engine and eliminates the need for major refurbishment between flights. The other really innovative feature of Raptor is its use of 'full-flow staged combustion' (FFSC). This is a particularly efficient engine design that was first tackled, without success, by Russian engineers in the 1960s. It wasn't until SpaceX's work with Starship and Raptor that an FFSC engine actually made it off the ground. This kind of design also has the advantage of creating a less extreme environment inside the engine's pipework.

Starship actually uses two different variants of the Raptor engine – one designed to give best performance at sea level and the other optimised for use in the vacuum of space. All 33 of the engines in the Super Heavy booster are sea level types, while the upper stage uses a mix of three sea level and three vacuum variants. Since it was originally conceived, the Raptor design has undergone a steady stream of refinements, and it's now on its third generation. The two most obvious trends have been in reduced weight, which has gone down from 2,000 kilograms for Raptor 1 to 1,400 kilograms for Raptor 3, and greater thrust, which has increased from 1.8 to 2.6 meganewtons.



Did you know?

engine per day

Raptor engines are used to launch SpaceX's giant Starship rocket

SPACEX STARSHIP

When SpaceX founder Elon Musk talks about Starship, he often focuses on the ultimate goal of using it to take humans to Mars. It's this long-term vision that has dictated some of Starship's most innovative features, such as the ability to refuel in space. It also influenced the choice of methane as a fuel, since it's a chemical that could be synthesised on Mars from subsurface water and atmospheric carbon dioxide. In the nearer term, Starship is likely to see less dramatic service as SpaceX's main workhorse.

Both the upper and lower stages of Starship use Raptor engines

METHANE AS A ROCKET FUEL

A historically popular fuel choice has been RP-1, a kerosene-based fuel. This is what the giant first stage of NASA's Saturn V used, as well as SpaceX's Falcon 9. Others, such as the Space Shuttle main engines, use liquid hydrogen. The latter is cleaner and more efficient, but it's more expensive and harder to handle because it has to be stored in liquid form at extremely low temperatures. In recent years, methane has emerged as a compromise between these two, being cleaner than RP-1 but cheaper and easier to handle than liquid hydrogen.

Fuel storage tanks are visible alongside the Starship launchpad in this photo

DO YOU KNOW? In July 2023, China's Zhuque-2 became the first methane-fuelled rocket to reach Earth orbit

INSIDE RAPTOR

Here's a simplified view of how this complex engine works

United Launch Alliance's Vulcan rocket also uses methane fuel

1 LIQUID OXYGEN IN
In order to burn, the methane needs an oxidiser – in this case pure oxygen that's stored in liquid form.

6 MAIN COMBUSTION
The engine's heart is the main combustion chamber, where methane and oxygen are combined at high pressures and temperatures.

Raptor's first test flights were carried out using the Starship upper stage only

3 OXYGEN TURBOPUMP
Before it's combined with the fuel, the oxygen is raised to a high pressure here.

2 FUEL IN
The methane fuel – also stored in liquid form – enters the engine here.

4 FUEL TURBOPUMP
The fuel is also raised to a high pressure in a separate turbopump.

5 PREBURNER
Small amounts of fuel and oxygen are burned separately to produce the power to drive the turbopumps.

7 EXHAUST NOZZLE
The hot exhaust gases are expelled at high velocities from this specially designed nozzle to generate rocket thrust.

8 COOLING PIPES
Cold, unburned propellant is circulated through these pipes to keep the nozzle from overheating.

SPACEX ENGINE POWER

TECH SPECS

ENGINE FAMILY NAME
Merlin

DATE DEVELOPED
2006

THRUST
981 kilonewtons

PRIMARY USE
Main engine

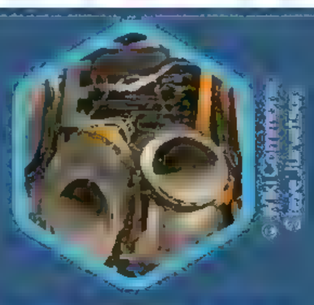
TECH SPECS

ENGINE FAMILY NAME
Kestrel

DATE DEVELOPED
2006

THRUST
28 kilonewtons

PRIMARY USE
Upper-stage engine



TECH SPECS

ENGINE FAMILY NAME
Draco

DATE DEVELOPED
2010

THRUST
400 newtons

PRIMARY USE
Spacecraft thruster

TECH SPECS

ENGINE FAMILY NAME
SuperDraco

DATE DEVELOPED
2012

THRUST
71 kilonewtons

PRIMARY USE
Launch escape engine

TECH SPECS

ENGINE FAMILY NAME
Raptor

DATE DEVELOPED
2016

THRUST
2.6 meganewtons

PRIMARY USE
Main engine

ENVIRONMENT

ENVIRONMENT

GREAT ANIMAL MIGRATIONS

WORDS AILSA HARVEY

Taking to the skies, sea or land, what drives certain animal communities to make long voyages across the globe?

DID YOU KNOW? In a 9,942-mile round trip, grey whales make the farthest of all mammal migrations

The animal kingdom is always on the move. Conditions in the wild can be unpredictable, with environmental disasters and ever-changing ecosystems causing species to flee their habitats. However, some moves occur on schedule, and many species have adapted to take advantage of whichever part of the planet suits them best at certain times of year. Animal migrations include any regular or seasonal movement of animals that also incorporates a return journey, forming a cyclic pattern. The animals proceed from one habitat to another to find better food availability, a more comfortable living climate or suitable locations to reproduce.

Did you know?

Depending on their size, method of movement and reasons for migration, animals travel a range of distances. And for some short-lived animals – especially insects – this venture takes most of their lifetime. Size doesn't always dictate a species' migration capabilities, though. Take the Arctic tern, for example. This is one of 4,000 regular bird migrators, enduring the longest migration of all of the world's animals. This bird, with a wingspan of just 64 to 76 centimetres, flies in a zig-zag pattern, covering 24,855 miles between the Arctic and Antarctic annually.

OCEAN MOVERS

Some of the seas' great migrators are baleen whales, sea turtles and devil rays. Many species of baleen whales travel from the colder waters they use for feeding for four to six months of the year to warmer waters for breeding. The warmer water is safer for whale calves, who have less insulating blubber, and also keeps their killer whale predators away. Sea turtles can migrate 9,942 miles in one year. These migrations are to find food, ideal temperatures and good nesting spots. Some turtle species, such as loggerhead sea turtles, find their way back to the exact beach that they were born on. Meanwhile, devil rays migrate annually in large groups of several thousand. These three-metre-wide creatures glide through the water as they migrate from Mexico's Yucatán Peninsula to Florida seeking food and sheltered waters.

Two humpback whales migrating to warmer waters surrounding Australia

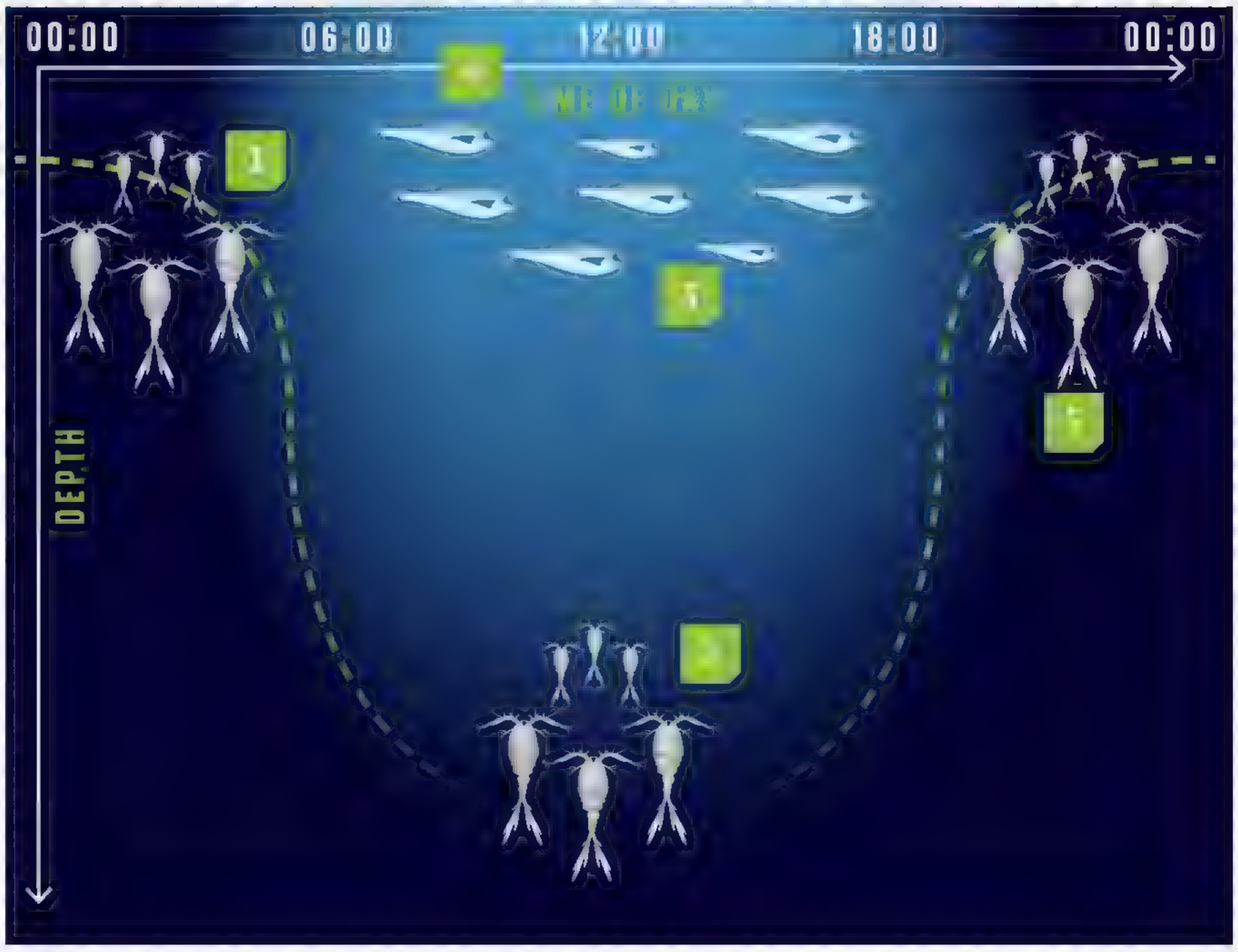
Zambia's straw-coloured fruit bats can travel more than 1,555 miles during a migration

FRUIT-FRENZIED BAT POLLINATORS

Zambia's straw-coloured fruit bats participate in the world's largest mammal migration every year between October and December. More than 10 million of these bats flitter into the skies as they travel from the Congo in Central Africa to Zambia's Kasanka National Park. The reason that these sizable bats – with wingspans up to 80 centimetres across – target the small national park is due to its abundance of Masuku fruits, or sugar plums. The adult bats weigh around 350 grams, and when they arrive at the park they eat twice their body weight of the sweet fruits in just one night. By the time they leave the park, after around three months, the bats will have demolished around a billion fruits. This gorging not only sustains their long flights across Africa, but helps in the pollination of plants and seed dispersal.

VERTICAL MIGRATION

By biomass, zooplankton perform the largest daily migration of any animal, rising from the deep and sinking again



1 CLIMB TO SURFACE
Zooplankton migrate towards the water's surface at night, where there's more food.

2 MIDDAY PROTECTION
While the Sun is shining on the water during the day, the zooplankton migrate to the ocean's depths. This protects their DNA from ultraviolet (UV) light.

3 PREDATOR AVOIDANCE
Fish that prey on zooplankton lurk at the surface. During daylight hours it is unsafe for zooplankton as they are visible to predators.

4 LIGHT-DODGERS
At just 100 metres below sea level, light is only one per cent of that at the surface.

5 WHAT ARE THEY?
Zooplankton are microscopic aquatic animals that include krill, sea snails and pelagic worms.

 During its 30-year life span, an arctic tern travels the distance of three trips to the Moon and back

Did you know?

Wildebeests born mid-migration join the march

MULTI-GENERATIONAL MIGRATION

The green darner dragonfly requires three generations to migrate across the US, but not all need to travel

7 CHEMICAL SIGNATURE
Hydrogen from the water they were born in is locked into their wings. The chemical structure of this element differs depending on the latitude that their bodies grew at. Scientists used this data to map this dragonfly species' movements.

2 GENERATION ONE
Between February and August, adult dragonflies that emerge in the south begin their migration north to reproduce.

6 COOLER TEMPERATURES
These dragonflies migrate north, as far as Canada. The 405-mile journey takes up most of their adult life, and soon after reproduction the dragonflies die.

3 GENERATION TWO
Between June and October, the offspring of generation one emerge as adults and return to the south.

5 OVERWINTERING SITES
In the winter months, green darner dragonflies live in the southern states, some migrating as far south as Mexico and the Caribbean.

1 ADULT EMERGENCE
Dragonfly eggs hatch as nymphs. When they emerge from the water and shed, an adult dragonfly is ready to migrate.

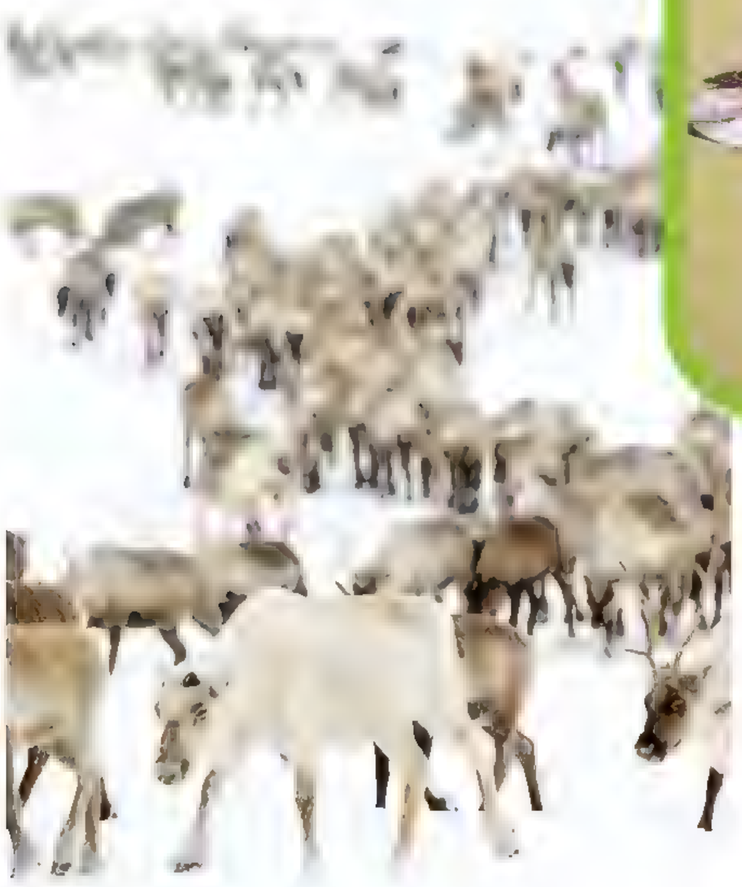
4 GENERATION THREE
The dragonflies born in the south between November and March don't need to migrate anywhere and live out their full lives in one location.

Christmas Island crabs are endemic to the island and have been named a protected species

THE CHRISTMAS ISLAND CRABS' SEA SCUTTLE

In the Indian Ocean, on Australia's Christmas Island, the native red crab species takes part in an annual spectacle as the entire population scuttles in synchrony from the forests to the shores. More than 120 million of the 11-centimetre-wide crabs cover the roads, rocks, forest floors and beaches as they migrate to the ocean to breed – amassing in a sheet of red shells as they do so. The male crabs begin migrating first, and females emerge to join the march along the way. This event takes place in October or November, in time for the first rainfall of the wet season. The red crabs breed before dawn, during a receding high tide and the last quarter phase of the Moon.

Reindeer usually migrate in long lines, going single file



TERRESTRIAL MAMMAL TRACKS

Caribou, or reindeer, earn the title for the farthest terrestrial mammal migration, covering an annual round-trip distance of 745 miles. These treks take place through Arctic terrain as caribou walk southwards and northwards across Alaska and Canada. In the spring, caribou usually migrate to the northern coasts to birth their young and avoid the insect pests that begin to emerge further south. Then, when snow begins to fall, a synchronised continent-wide migration takes place southward to find more sheltered areas. Over 620 miles makes a huge difference in the availability of moss and lichens to feed on.

However, not all caribou species migrate. There are two gene subgroups that materialised during the last ice age, when a large ice sheet divided reindeer populations. Those north of the ice sheet were living in areas with few trees, requiring them to move to less snow-covered land in the winter. However, caribou living separately in the south were in forest landscapes, where trees protected food from the snow. As a result, today some caribou migrate, while others have evolved to stay put.

3 ATLANTIC AMERICAS

The red knot bird flies the full 9,320-mile length of this flyway, from Canada's Arctic Archipelago to the tip of South America, twice a year. The ocean crossing at the centre – between North and South America – is a greater distance compared to the other American bird flyways. Birds such as the blackpoll warbler fly for 88 hours to cross over the 1,864-mile ocean gap. Before migrating, the warbler doubles its body mass. It has evolved an efficient metabolism to maintain energy and loses just 0.06 per cent of its weight as every hour goes by.

1 PACIFIC AMERICAS

This flyway covers the northern Arctic tundra and the west and southernmost tip of South America. One species that follows this migratory path southwards is the cackling goose of the remote Aleutian Islands. The geese fly along the coastline towards California, where they stay over winter.

2 CENTRAL AMERICAS

At the centre of this flyway is the Gulf of Mexico. Some species fly straight across this body of water, while others trace the coastline for a safer route. Over 380 species use this flyway. One of the smaller species is the ruby-throated hummingbird. These birds weigh 3.5 grams but are some of the bravest that cross the centre of the Gulf of Mexico. Ruby-throated hummingbirds fly for 25 hours without rest to complete this crossing.

BIRD FLYWAYS OF THE WORLD

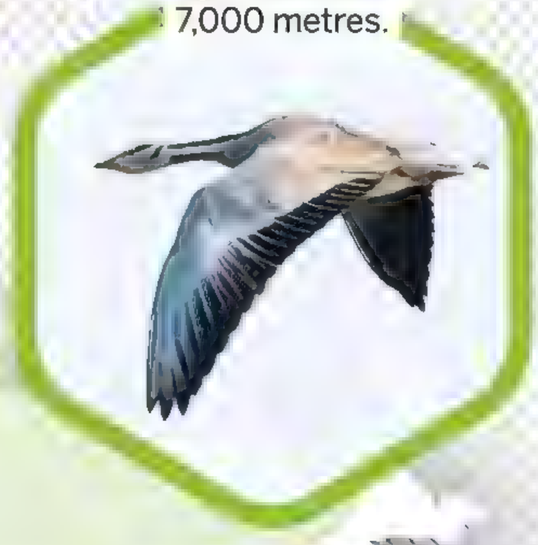
Most of the planet's migratory bird species follow the paths of these eight main flyways

1 EAST ATLANTIC

Many Arctic birds follow this flyway southwards for the winter, settling in West Europe and West Africa. During autumn months, masses of Arctic waterbirds from Canada, Iceland and Greenland gather in Western Europe. West Europe is the end location for birds such as ducks, geese and swans, while 250,000 soaring birds like kites and eagles make the longer journey into Africa, across the Strait of Gibraltar.

7 CENTRAL ASIA

Central Asia is the shortest of these eight flyways, as it doesn't cross into the Southern Hemisphere. Birds that follow this path into India either avoid the high mountains of the Himalayas, entering at either end of the Tibetan mountain range, or are capable of flying at very high altitudes. Bar-headed geese are an example of one species that can clear many of the mountains of the Himalayas. These geese have the highest migration flight in the world, soaring at altitudes over 7,000 metres.



Did you know?

Hyperphagia is the state of overeating before a bird migrates

5 BLACK SEA AND THE MEDITERRANEAN

This flyway connects the Russian Arctic and North Africa. For birds that migrate across its entirety, the Mediterranean Sea is the biggest challenge. Luckily there are 'land bridges' in this area providing stop-off opportunities. Birds migrating from Italy can use the Strait of Messina to Sicily, while others arrive in Africa via Malta.

6 EAST ASIA AND EAST AFRICA

Birds that use this flyway swerve westwards during their southerly migration to avoid the Himalayas' mountain barriers. In addition, Africa can sustain a greater influx of bird species than the smaller landmass of India. One bird that endures an especially long migration due to this detour is the willow warbler. They travel 7,020 miles, from northeast Siberia to South Africa, which is the longest journey taken by any songbird.

8 EAST ASIA AND AUSTRALASIA

Over 50 million migratory waterbirds use this flyway. Some, like the bar-tailed godwit, make impressive journeys over 6,200 miles. The bar-tailed godwit flies from Alaska to New Zealand, which is the longest non-stop flight of any bird. This species also holds the record for the longest journey made without stopping to feed by any animal.

ANATOMY OF A COMPOST HEAP

WORDS: ALICE HARVEY

How the natural process of composting converts your leftovers into valuable fertiliser

Leftover food, garden trimmings and other organic waste items don't need to be discarded. Instead they can be recycled in a process called composting. Composting is the breaking down, or decomposition, of organic material into nutrient-rich soil. After decomposition, these materials turn into organic molecules made up of carbon dioxide, water, simple sugars and salts. Compost heaps are places where this process is accelerated from years to months or even just a few weeks.

Composting mostly takes place outdoors, and there are two main types: cold, or passive, and hot, also called active compost. Cold composting is much slower but is easier to manage. All you need to do is add the right materials and allow the natural process to take place. The soil created from this process usually can't be recycled for at least one year, as much of the decomposition takes place slowly without oxygen.

Hot composting is more efficient, but requires you to maintain consistent layers of carbon-rich and nitrogen-rich materials while optimising the water and oxygen levels regularly. The ideal temperature for quick active composting is 55 to 60 degrees Celsius. This temperature is achieved when the heap is well aerated with peak composting conditions. Adding pipes into the top of a compost heap is a simple way to ensure air is entering the middle of the soil.

DO YOU KNOW? Australian brushturkeys build compost heaps in the wild to incubate their eggs in

A RECIPE FOR RICH SOIL

What ingredients work best in a compost heap?

1 ALTERNATING LAYERS
A successful compost heap has alternating layers of dry, carbon-rich 'brown' items and wet, nitrogen-rich 'green' items.

2 AIR
Larger items add air pockets. Air is needed for essential microbes to survive.

3 MOISTURE
Compost should be between 40 and 60 per cent water.

4 FRESH GRASS
Grass clippings are high in nitrogen, which increases reproduction in microorganisms.

5 BOKASHI SOIL
The soil from bokashi – a process that breaks down food waste by fermentation – can be added to compost to increase friendly microbes.

6 FOOD WASTE
Scraps of food can be completely broken down into compost in just a few weeks.

7 EGG TRAYS
The natural materials in egg trays break down quickly to make rich fertiliser.

8 DRY FLOWERS AND LEAVES
Dry plant matter is high in carbon. The best leaves to use are those from ash, maple fruit, poplar and willow trees.

9 VACUUM CONTENTS
The dust from a vacuum cleaner has some fast-composting materials such as human and pet hair and skin flakes.

10 DRY GRASS
Dry grass is a useful brown layer if it hasn't been treated for a couple of weeks.

11 WOOD CHIPS
Pieces of wood are rigid and create air pockets in the compost pile.

12 CARDBOARD
Cardboard and paper can be soaked and shredded to add moisture to the compost.

WHAT IS VERMICULTURE?

Another term for vermiculture is worm composting, which involves using worms to break down organic matter into nutrient-rich soil. Just by existing in the soil, worms improve the health of soil and break down garden waste. Additionally, the soil they produce is ideal for growing more plants that can be given back to the worms as food. Vermiculture can break down more waste than traditional composting. This is because worms eat a wide variety of products, such as meat and dairy. In standard compost, these foods take too long to decompose, and infectious bacteria such as *Escherichia coli* and *Salmonella* can accumulate. Worms can demolish these quickly, but adding these foods still isn't recommended as they can create strong and unpleasant smells.

Vermiculture experts recommend adding worms and waste to compost in equal weights for the best results

Did you know?
Farmers have been composting for 12,000 years

DECOMPOSER FOOD WEB

How the various creatures in the food web help to break down waste

ENVIRONMENTAL BENEFITS

Around one-fifth of all household waste is food – the second-largest waste type after paper. Without composting, almost all of this food ends up in landfills. Landfills aren't sustainable; they pollute the natural composition of the ground and release pungent odours and greenhouse gases such as methane. One demonstration of the impact large-scale composting can have on landfills is seen in San Francisco. In 2009, composting became a requirement for everyone in the city. By separating their compostable waste, the city prevented 80 per cent of waste items from going to landfills. Composting also produces much healthier soil, with the organic matter holding soil together better, retaining more water and increasing nutrients naturally so that fertilisers aren't needed. Many plants can thrive in the soil made by composting, and the soil traps more carbon dioxide, which would otherwise accumulate in the atmosphere.

DID YOU KNOW? Compost heaps can reach 23 degrees Celsius in just a few days

1 FOOD WASTE
Compostable leftovers can be shredded and consumed by the compost pile's primary consumers.

2 ACTINOMYCETES
These bacteria thrive in soil with high alkaline pH levels. Actinomycetes break down woody materials, cellulose and proteins.

3 FUNGI
Fungi can break down complex materials so that bacteria can begin the composting process quicker.

4 SPRINGTAILS
These insects are pests to plants in large numbers, but eat the fungi growing within the compost.

5 MOULD AND BEETLE MITES
Transparent mites are attracted to the mould that grows in compost.

6 FEATHER-WINGED BEETLE
Very common in compost heaps, they live off fungal spores and leaf litter.

7 TERTIARY CONSUMERS
At the top of the compost pile food chain are centipedes, ground beetles and ants. These help control pest levels.

8 BACTERIA
Microorganisms break down organic matter. They release heat as they break down material, making a warm habitat for other creatures.

9 ROUNDWORMS
These are the most abundant invertebrates in compost soil. They eat bacteria, fungal spores and each other.

10 PROTOZOA
Protozoa are single-celled animals that live in water droplets. They have a small role in decomposition and consume bacteria and fungi.

11 ROTIFERS
These multicellular microbes break down organic material and eat bacteria.

12 WHITE WORMS
When you notice more white worms in your compost, it's a sign of acidic conditions. These worms aid decomposition by breaking down starchy foods.

13 SNAILS AND SLUGS
These eat leaves and plants in the compost to break them down.

14 EARTHWORMS
Earthworms feed on fresh and decaying matter. Their waste mixes nutrients through the compost and helps to aerate the soil with oxygen.

15 SOWBUGS
These small bugs eat vegetable matter. Decaying produce is their main food source, so they like to live in compost.

16 MILLIPEDES
These critters do much of the shredding work in compost heaps. They consume up to ten per cent of the leaf litter.

17 FLIES
Placing food scraps further towards the bottom of compost heaps can reduce flies. However, they assist in decomposition and their eggs are often consumed by other creatures.

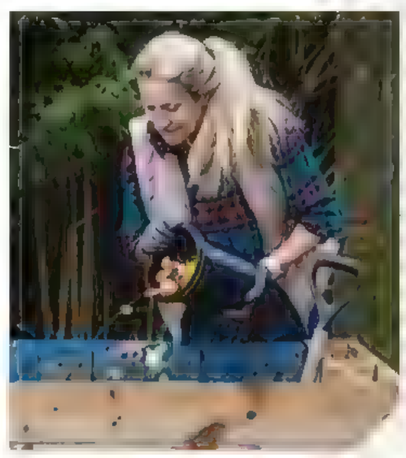
Did you know?

What is a good ingredient to compost

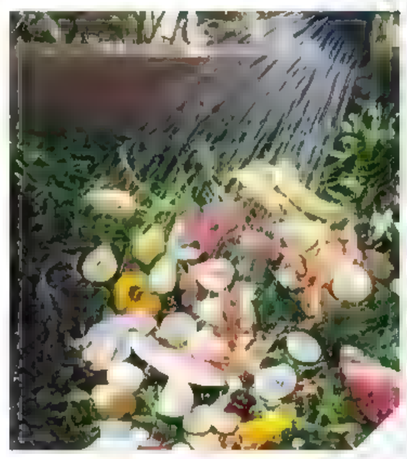
HOW TO MAKE COMPOST

1 CHOOSE THE RIGHT PLACE
A dry area away from direct sunlight is an ideal spot. You should consider somewhere far from your home but still near a source of water, like a garden hose.

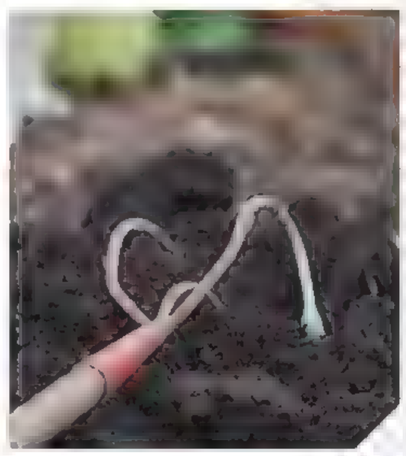
2 ADD ITEMS
Using items from the recipe on the previous page, start constructing your compost pile in layers. These should each be around ten centimetres deep.



3 MOISTEN THE SOIL
As you build the layers, keep adding water every so often. This will ensure the soil is evenly damp throughout.



4 KEEP THINGS MOVING
Mixing the compost speeds up the decomposition process. Do this at least once every couple of weeks using a garden rake or similar tool.



5 HAVE SOME PATIENCE
Make sure the soil remains damp, but not too wet, like a sponge after being wrung out. It will take around two to four months for matter to decompose when regularly mixed.

Illustration by Adnan Mann

ENVIRONMENT

DEADLY DINOSAUR DISEASES

From prehistoric parasites to ancient airborne infections, discover the illnesses that plagued these giant creatures

WORDS: JACK PARSONS

DO YOU KNOW? You can explore hundreds of CT scans of dinosaur bones from the University of Texas at digimorph.org

We all know the *Tyrannosaurus rex* terrorised *Triceratops* on land. Many of us can picture Pterosaurs diving down from the skies to snatch smaller prey. A few might even know the *Mosasaurus*, the leviathan that ruled the ancient oceans. But while these mighty carnivores loom large in how we imagine the age of dinosaurs, there was a far greater threat that we forget – an invisible foe that would strike without warning and killed millions more creatures in the Mesozoic era than any other: illness.

It's no surprise that dinosaurs got sick. They were living, breathing creatures just like us. But we know very little about what actual diseases made these ancient creatures ill. This is because you can identify signs of injuries like broken limbs and battle scars in the fossil record – often with little more than a magnifying glass – but diagnosing illness is far more difficult. It's not just that bacteria and viruses are microscopic. Diseases mostly attack internal organs, which are made of fleshy soft tissue and usually rot too quickly to be preserved.

On rare occasions, some dinosaur flesh remains. The remnants of a ravenous raptor's guts were discovered in China in 2022 and the brain tissue of an *Iguanodon*-like herbivore in the UK in 2016. These were likely preserved only because the dinosaurs' bodies were submerged in bog-like water. But more often than not, paleopathologists – researchers of ancient diseases – have to make do by assessing fossilised bones for rare signs of severe illness.

However, modern technology is helping these researchers delve deeper for clues. 20 years after it was invented for use in medical diagnosis, computed tomography scans, or CT scans as they're better known, are being used to see inside fossils. This process uses X-rays, but the results are much more detailed than the X-ray you might get at the hospital if you broke your leg. They are high-resolution 3D reconstructions that you can zoom in and out of to fully explore the structures. This can reveal lesions and

Palaeontologists scan fossils with higher X-ray doses than you could use on a living patient

DINOSAURS BATTLED CANCER TOO

New research suggests dinosaurs could suffer from cancer. The evidence was dug up in 1989, but it just wasn't recognised until recently. A *Centrosaurus apertus* was uncovered in Alberta, Canada, with a misshapen shin bone. Experts at the time thought it was a poorly healed injury. But another team of scientists – bringing together pathologists, a surgeon and a radiologist as well as palaeontologists – reexamined the fossil in 2020 using high-resolution X-ray CT scans. They diagnosed the deformity as osteosarcoma, an aggressive bone cancer also found in humans.

This isn't the only example of cancer in the fossil record. Tumours have also been found in *T. rex* and duck-billed *Bonapartesaurus*. But both appeared to be benign, meaning they didn't seriously affect the dinosaur's day-to-day life. Instead, this is the first example of a malignant tumour in dinosaurs, meaning that the cancer could have spread to different parts of the body and become deadly.

The *Centrosaurus* was a slightly smaller cousin of *Triceratops*

deformities buried in bones that are telltale signs of infections but would be unidentifiable from the outside.

As palaeontologists expand the techniques they use to analyse fossils, they're also drafting different kinds of experts to help them. Doctors and radiologists have helped by comparing CT scans of fossils with human medical records to look for similarities, while veterinary scientists have shared their knowledge of how diseases manifest in other reptiles like crocodiles, as well as birds, which evolved directly from dinosaurs. This new approach is overturning previous research. Fossils that were thought to be twisted bones or bite marks proved to be far more interesting. By diagnosing these primordial illnesses, we learn more about the dinosaurs they afflicted. We better understand their biology as we discover illnesses they share with modern-day animals. The types of diseases and how they may have spread also hint at how dinosaurs behaved with members of the same species, as well as the relationship between predators and prey.

DUCKBILL BONE DISEASE

Some 70 million years ago, a Hadrosaur lived alongside a shallow sea covering what is now New Jersey. It had a real pain in the arm, which two centuries after it was unearthed we know was due to septic arthritis – the first known case in a dinosaur. This is a common bone disease that often develops when an injury becomes infected. A CT scan revealed signs of erosion within two arm bones, with a porous texture instead of healthy, dense bone tissue. On the outside, both bones had bulges, and spurs of new bone had formed. In fact, when excavated the pioneering 19th-century palaeontologist reported that the two bones were fused, but the brittle fossil had broken apart.

The Hadrosaur was a rare find on the US' East Coast, which has few fossils

While Dolly's exact species is unknown, they were related to *Diplodocus* and *Brontosaurus*

A VERY SAURO-THROAT

Imagine how bad a tickly throat must feel if your neck is 25 metres long. There wouldn't be enough chamomile tea in the world to soothe it! A sauropod nicknamed Dolly had a serious case of the sniffles. This included a cough, trouble breathing and a fever, according to scientists. The infection was so severe that it marked the creature's neck vertebrae, which we can still see in the fossil today. While Dolly is the first confirmed case of a dinosaur with an airborne illness, possible signs of tuberculous were found on the rib of a *Titanosaur*, another sauropod, in 2021.

ANCIENT AUTOPSY: DOLLY THE DINOSAUR

This respiratory infection would've been a real pain in the neck – and the air sac

1 LAST BREATH
Dolly inhaled an airborne disease, possibly spores from a fungus that would have thrived in the humidity of primaeval Montana.

2 DOWN WE GO
The disease was carried on Dolly's breath down their long windpipe and into the lungs, but it didn't stop there.

3 BREATHING SPACE
Like birds today, air circulated through hollow bones and inflatable organs called air sacs. These helped make Dolly's colossal frame lighter without sacrificing too much strength.

4 NO SIGNS OF RECOVERY
The disease lodged in an air sac within Dolly's thorax. Unfortunately, the infection was likely chronic and possibly fatal.

Did you know?

Leprosy is the oldest known human disease

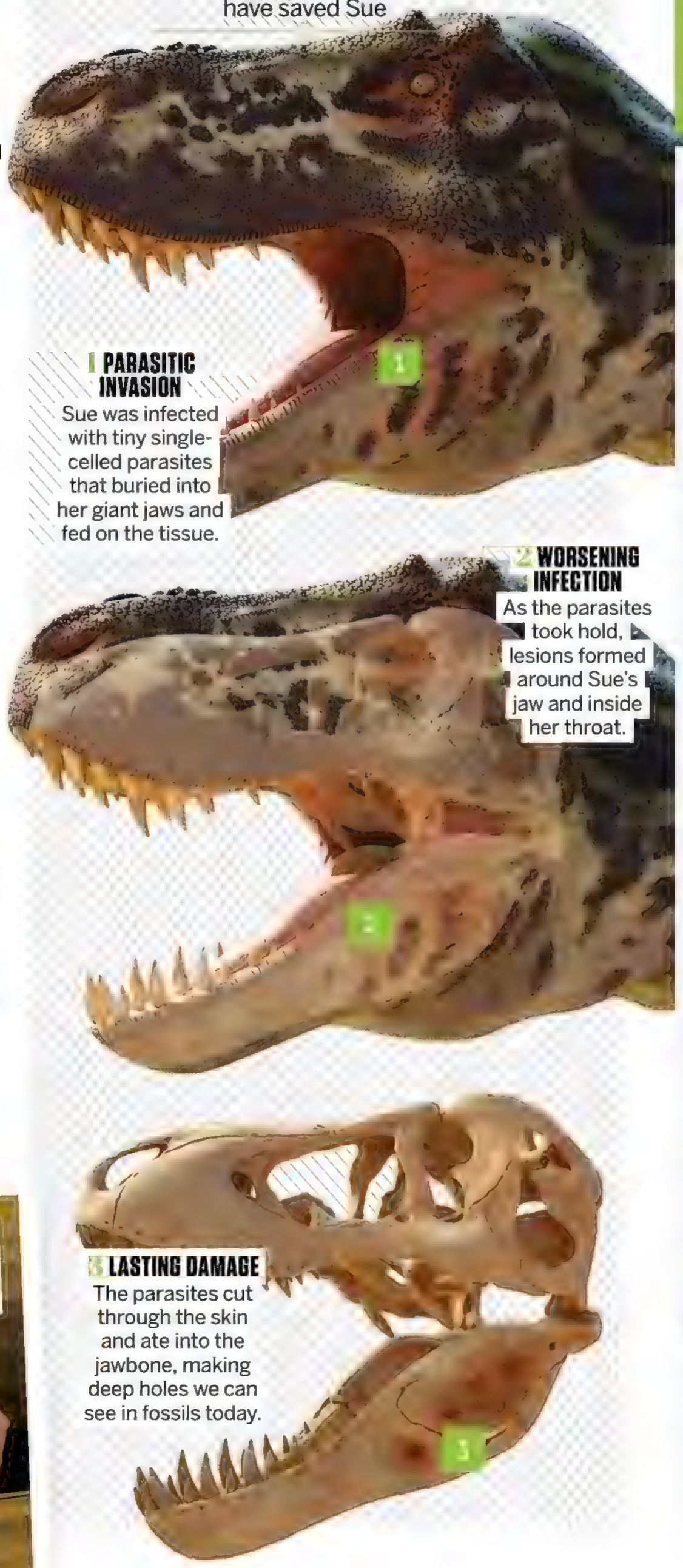
T. REX'S TERMINAL TOOTHACHE

The *T. rex* was the king of the Late Cretaceous period. It boasted a mouthful of banana-sized teeth and a biting force of 3,500 kilograms – that's like the impact of three small cars. But these champion chompers were also the apex predator's weak spot. "Some of the world's most famous *T. rex* specimens have these holes in their jaws," says Dr Steve Salisbury from the University of Queensland. "Some specimens look like Swiss cheese." Working with a small team, Salisbury examined over 60 *T. rex* fossils. This included Sue, one of the best preserved skeletons, which is on display at Chicago's Field Museum.

"We now believe that these holes are caused by an infectious disease called trichomonosis," Salisbury says. This is an illness caused by microscopic parasites. Many pigeons carry it today but are immune. But hawks and falcons that eat pigeons can get very sick, developing lesions in their lower beaks. It's possible that *T. rex* caught the infection from their prey too. But the fierce theropods were also known to fight among themselves. "We don't think it's a coincidence that a significant number of adult tyrannosaur specimens show both face-biting marks and evidence of a trichomoniasis-like disease," Salisbury says. "Fighting, and specifically head-biting, would have been an ideal mechanism for spreading the disease among tyrannosaurs." However it was caught, the infection would have meant a slow, painful death. It would have made it harder and harder for the creature to eat until it starved.

ANCIENT AUTOPSY: SUE THE T. REX

No trip to the dentist would have saved Sue



5 FACTS DIFFERENT DINO DEATHS

1 GETTING EATEN
It was a dino-eat-dino world. We know of at least 100 meat-eating dinosaurs, ranging from the crow-sized *Microraptor* to the enormous *Spinosaurus*, which at 14 metres long was three times the size of an African elephant.

2 GETTING BITTEN
You might consider yourself lucky to escape a hungry carnivore. But even a scratch could be deadly if it became infected with germs. A towering sauropod in China was discovered with signs of a pus-marked injury caused by either tooth or claw.

3 BREAKING BONES
Broken bones litter the fossil record. While many show signs of healing, meaning the creatures survived, others show signs of becoming terminally infected. But not all of these injuries were from combat. Evidence suggests theropods like the *T. rex* were prone to falling over.

4 NATURAL DISASTER
Geology suggests that volcanic eruptions were commonplace 65 to 70 million years ago, which would have been explosive and devastating. While a herd of thousands of *Centrosaurus* were struck down in a flood 77 million years ago, possibly caused by a tropical storm.

5 ASTEROID ANNIHILATION
It only took one asteroid strike 66 million years ago to wipe out the dinosaurs. The impact caused catastrophic wildfires, earthquakes, tsunamis and a dust cloud that blocked sunlight for a year.

HOW TO SURVIVE THE AUSTRALIAN OUTBACK

From bush tucker basics to sourcing trapped water and combating crocodiles

WORDS **AILSA HARVEY**

Around 40 lives are lost in the Australian Outback every year. It's a land that only some of the most resilient of Earth's plants and animals are capable of calling home. Aboriginal tribes have mastered survival in the Outback over the course of 65,000 years, learning to live in the unique environment and source meals from sparse and poisonous vegetation. Most tribes respect the power of nature in the Outback to give and take life, and have become wiser through each generation. Their innovative methods that utilise the resources around them include extracting parts of plants as medication for illness and animal-inflicted injuries. For example, the leaves of the emu bush are used to wash cuts, and have demonstrated similar natural strength to modern antibiotic medication. Meanwhile, the bright-orange desert mushroom works to treat oral thrush when held in the mouth.

Many people who visit the Outback each year are foreigners to the unforgiving landscape. Despite covering 2.1 million square miles – more than 70 per cent of Australia – only five per cent of the country's population live there. Often visitors fear the animals that have claimed the land, but heat and dehydration are the two biggest killers in the Outback. Your body can use up more than four times as much water during summer there, as daytime temperatures usually hover around 40 degrees Celsius. Being dehydrated in this environment can lead to death in a matter of hours. And any other safety precautions you may be taking lose effectiveness when dehydration diminishes your ability to think clearly. Without the extensive knowledge of Australia's ancestors, visitors should enter the Outback as equipped as possible, both mentally and physically.

Did you know?

In winter, Outback temperatures drop below freezing

DID YOU KNOW? In the Northern Territory there are 0.16 people per 1,000 square metres

ESSENTIAL EQUIPMENT

When exploring the Australian Outback's expansive desert landscape for long periods of time, possessing a few key survival items can make the difference between life and death. Your survival toolkit should include navigation devices, water purification appliances, emergency communication technology and protective camping items. Portable water filters are vital for situations when you run out of clean drinkable water. The Outback is known for its arid conditions, so being able to remove dirt and germs from the limited natural water reduces the chances of severe dehydration.

With few large geographical landmarks, GPS devices will be your saviour, keeping you travelling in the right direction. If this fails, a compass is also reliable. Large areas of the Outback don't have mobile phone network coverage, so satellite phones are useful for emergency communications. Finally, protection from the weather and animals should be considered. You will need a weather-resistant tent and moisture-wicking clothes to protect your skin from the Sun and keep you cool. Incorporating many thin layers is an effective way to regulate temperature.

Fire-starting gear is useful for cooking food, boiling water and as a light source

Outback soil is rich in iron, giving it a reddish hue

WHERE'S THE WATER?

The Great Artesian Basin is a 650,000-square-mile underground freshwater resource

1 EULO
An outflow of the basin's water can be found near this small town in the form of mud springs. Mud and water are forced upwards through fissures in the ground. The mud is thermally heated and mineral-rich.

2 WARREGO BORE
This bore, or well, was drilled in 1890 as part of 541 that were completed by 1897 to access the basin's water. Today there are over 50,000 bores.

3 GREAT DIVIDING RANGE
This mountain range is a recharge area for the Great Artesian Basin. Mountains intercept precipitation and water is able to seep into the basin through the soil.

4 LAKE EYRE
Covering 3,668 square miles, this lake is the biggest in Australia and lies directly above the Great Artesian Basin.

5 COOPER CREEK
This creek recharges the basin as its water enters the soil.

6 SPRINGSURE
This town is famous for its many permanent springs, which release the basin's water.

7 MOUND SPRINGS
Mound Springs is an area abundant in the basin's natural springs, around which mounds have formed. Water is released from the top of the mounds and pours over the landscape.

Cairns
Alice Springs
Brisbane
Sydney


This is what kangaroo footprints look like in the sand

FOLLOWING FOOTSTEPS

If you ever lose your way in the Australian Outback, it's worth examining the ground. If you come across the tracks of humans or animals, this can lead you to civilisation, or at least to hydration. Following previously trodden paths can return you to established routes, while some animal tracks will inevitably guide you to a water source. The tracks of wild pigs and kangaroos will lead to water, as they need to drink regularly. These trails should be followed downhill if you're in search of water. For unknown animal tracks, those that appear to have been regularly trodden are most likely to be water routes.

BUSH TUCKER BASICS

WATTLE LOT OF USES

For over 50,000 years, the golden wattle plant has aided Australians' survival as food, medicine and tools

7 TOOLS AND MATERIALS
The gum inside the plant has been used as glue, and the branches and bark utilised for firewood.

6 FRAGRANT FLOWERS
The wattle plant's flowers can be eaten straight from the tree, and are often used to make flower fritters.

1 POD POUNDING
The seed pods can be ground into flour and used to make dough.

2 BUSH POPCORN
Roasting raw wattle seeds over a fire until they pop gives the seeds a light texture and sweet flavour.

5 GREEN SEEDS
When green, golden wattle seeds can be cooked like peas.

4 BARK
The bark is high in tannins, which can be used as a remedy for indigestion.

3 RESILIENT GROWTH
Golden wattle is a widespread food source, as it can survive droughts and favours hot climates.

Did you know?
Witchetty grubs live on the roots of the witchetty bush


Traditionally, witchetty grubs are eaten live and raw

EDIBLE INSECTS

It might not be everybody's first meal choice, but when food is scarce you can look to creepy crawlies for energy and nutrients. Insects have been a bush tucker delicacy for thousands of years, but it requires knowledge of which animals are edible. The main groups of edible insects are witchetty grubs, bogong moths and honey ants.

Witchetty grubs are the caterpillars of the giant wood moth, and were historically a staple food in Aboriginal communities due to their impressive energy content. By weight, the insects have 15 per cent protein and 20 per cent fat. Witchetty grubs are generally eaten raw or lightly roasted. They have a creamy texture and nutty, egg-like taste when raw, but when cooked they taste more meaty.

In New South Wales, large bogong moths have long been used for culinary purposes because of their abundance and high fat content. They carry out seasonal migrations and are easy to collect in large numbers as they typically rest on each other. Traditionally, these moths are cooked and ground to a paste.

In contrast to the larger, juicier creatures, ants seem like a strange meal choice for survival. However, as they are found in all areas of the Outback, they make a reliable meal. Ants are a good source of protein, relatively easy to catch and have unique flavours among species. Green ants have a citrus flavour, while honey ants have filled their stomachs with honey and taste sweet.

5 FACTS TOXIC FOODS

1 BUSH TOMATO

The fruits of the bush tomato can be a tasty snack, but make sure they are ripe. When they are still green they are poisonous, as they contain the toxin solanine.

2 STRYCHNINE FRUIT

The small, orange spheres that hang from this tree may look like an appetising juicy fruit, but contain highly poisonous seeds. Eating these can cause paralysis or death.

3 FINGER CHERRY

Eating this fruit has been linked with permanent blindness. Some people still eat these without any ill effects, but it is recommended to stay away from this fruit.

4 KANGAROO APPLE

All parts of this plant are poisonous when green and unripe. However, when they are ripe they are soft and edible.

5 BURRAWANG

This cycad is poisonous until it undergoes thorough treatment. Aboriginal Australians learned that the plant is made edible after the seeds are pounded and soaked in regularly changed water for weeks.

DEADLY COMPANY: OUTBACK ANIMAL GUIDE

1 SALTWATER CROCODILES

Saltwater crocodiles aren't fussy when it comes to their prey, and will take the opportunity to launch their powerful jaws in your direction if you get too close. They inhabit the coastal waters of Australia, but also venture inland to swamps, marshes and lakes. They're expert ambush hunters and are well-camouflaged in the muddy waters, lurking just below the surface. As they are difficult to see in a landscape, avoid swimming in waters of unknown risk – especially in Northern Australia, where these crocodiles are most common.

LIFE SAVING LESSON

The jaws of a crocodile are near-impossible to escape from. But if a crocodile has hold of you, your best chance of survival is to aim for vulnerable body parts like the eyes and head. If you are dragged underwater and are spun in a move called a 'death roll', you should try to roll with the crocodile to prevent your limbs from being damaged. If you survive a crocodile bite, the immediate first-aid response is to stop the bleeding and remove infection through antibiotics.

2 DEADLIEST SNAKE

The inland taipan is the most venomous snake in the world, trawling the Australian Outback for its next prey. This hardy reptile is well-adapted to high temperatures and dry landscapes. Beware of small cracks and crevices in the ground and rocks, as they shelter in these spaces, away from the sunlight and your gaze. Just one bite from the inland taipan releases enough venom to kill 100 people. To identify this snake, look out for large to medium-sized snakes of yellow or brown colour, a rectangular-shaped head and large, dark eyes.

LIFE SAVING LESSON

Despite their deathly reputation, the inland taipan doesn't typically approach humans. However, if you get bitten, remain as calm as possible and at rest. This prevents venom from travelling quickly around the body. Apply tight bandages to the bite site or firm pressure if the site can't be bandaged.

3 WIDESPREAD ARACHNIDS

The redback spider is one of Australia's most poisonous spiders. They can be encountered in urban areas as well as the extreme climates of the Outback. Distinguished by the red stripe stretched over its back, the spider is responsible for around 2,000 reported bites annually. The females are capable of the nastiest bites, but they don't typically cause death in adults. Instead, the venom attacks the nervous system and causes intense and long-lasting pain.

LIFE SAVING LESSON

The bite of a redback has more severe consequences for children, so younger victims need to seek medical attention with more urgency. The bitten individual should lie down and rest, while another person can apply a cold object to soothe the pain. Antivenom is given by doctors to treat this bite.

4 AGGRESSIVE STINGERS

The desert scorpion is one of the most aggressive scorpions in Australia. They measure around 8 to 11 centimetres long and are widespread in the central Outback regions of the country. The scorpion makes deep burrows in the sand to protect itself from the Sun and emerges mostly after nightfall. If provoked, this animal is known to be highly aggressive towards humans, unleashing a sting from its tail and causing inflammation that remains for many hours. Signs of a defensive scorpion include standing upright, a high tail and open pincers, ready to snap.

LIFE SAVING LESSON

Scorpion stings in Australia don't typically cause death, but it's possible for them to instigate a deadly allergic reaction. You should wash a sting straight away and apply antiseptic to prevent any infection. A cold pack and painkillers can be used to reduce the pain, though you should seek medical assistance if the pain doesn't subside.

Redback spiders are native to Australia

DID YOU KNOW? 30,000 people go missing in Australia every year – the equivalent of one person every 18 minutes

An adult saltwater crocodile has an average of 66 teeth

Inland taipans can kill a person in 45 minutes

2

Desert scorpions can live for up to 20 years

1

WATCH THE WEATHER

The Australian Outback is a vast expanse of mostly flat, dry terrain. Being inland, the ocean can't help moderate temperatures and weather changes. Meanwhile, lying relatively close to the equator means the environment receives intense direct sunlight and long periods of high temperatures. Some of the most dangerous weather conditions experienced in the Outback are wildfires, heat waves, dust and sandstorms, sudden rainfall in the northern regions and droughts.

You can spot an incoming dust storm by observing the sky's colour. If it changes colour and adopts a red hue, this is an indication that a dust storm may be approaching. Changes in animal behaviour can also alert you to incoming weather. Many animals have heightened senses to give them a better chance of survival. If all the surrounding animals take shelter, it's unlikely to be coincidental.

When dust is in the atmosphere, blue light is scattered and the sky appears redder

ANATOMY OF A SINKHOLE

Did you know?

Sinkholes are a major problem in Florida, where the limestone bedrock is covered by sand and clay.

Sinkholes are cavernous pits that appear when the ground's surface collapses. How do these deadly depressions occur?

WORDS **PROFESSOR IAIN STEWART**

Florida is a US state collapsing in on itself. Amid the city streets, quiet suburbs and citrus groves, gateways are opening up into the real, hidden Florida. Virtually the whole of the Sunshine State, from the Keys in the south to the border with Georgia in the north, is underlain by a strange, cavernous underworld. That's because Florida is built on a vast platform of limestone bedrock. Just tens of metres below ground, a vast underground river system – the Floridan aquifer – channels billions of gallons of groundwater through subterranean passageways. This buried arterial network provides most of Florida's fresh water. It keeps the grass green, fills the many swimming pools and slakes the thirst of its residents. But the water is also eating away at Florida's soluble limestone foundations.

> "The water is eating away at Florida's limestone foundations, and that means the land above is sinkhole country"

And what that means is that the land above is sinkhole country.

Sinkholes mostly form by acid-tinged rainwater slowly eating away the limestone and washing soil and sediment into the cavities. The result is a pockmarked landscape of gentle pits and depressions that can flood to give residential estates much desired ornamental lakes. But some sinkholes form with the sudden collapse of the ground above caves and caverns. These 'cover-collapse' sinkholes are the deadly threats that lurk in the Florida subsurface. The trigger mechanism for these sinkhole trapdoors is still a mystery. Some are caused by too much water. Hurricanes can dump tonnes of water on the land over a matter of hours, weighing down the soil and collapsing the roofs of caves below. Others snap open from too little water. Drought years or groundwater pumping can reduce pressure in water-filled voids, causing unsupported sides to implode.

But the main reason for Florida's growing toll of sinkhole damage is ourselves. The lure of Florida sunshine is drawing ever more people to the state, and our urban sprawl is advancing into wild land primed with sinkhole traps. In the past they would have gone unnoticed... but not now.

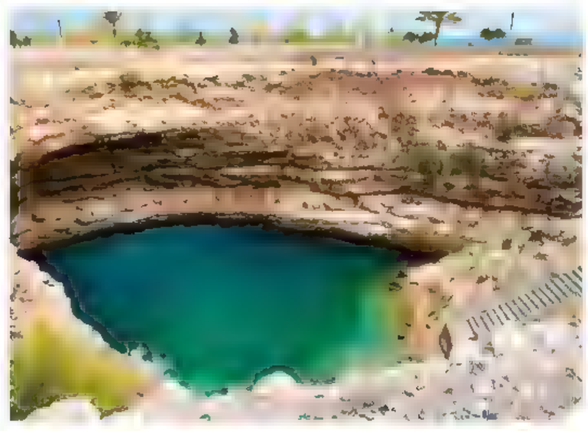
OTHER SINKHOLES AROUND THE WORLD

GUATEMALA

Florida may be the sinkhole capital, but other places have their deadly equivalents. In 2010, a sinkhole killed at least 15 people in Guatemala City. It opened in the wake of Tropical Storm Agatha, occurring just three years after a similar sinkhole in the city in 2007 killed three people.

BOSNIA

Sinkholes are a common problem in Eastern Europe, where much of the landscape is underlain by soluble bedrock such as limestone. In November 2013, the residents of Sanica woke up to discover that an immense sinkhole had drained their village pond.



OMAN

Sinkholes aren't always traumatic. Bimmah Sinkhole in Bayt al-Afreet is often cited as one of the world's most beautiful sinkholes. It is a tourist attraction in its own right, as holidaymakers flock to swim in its emerald-green waters.

DID YOU KNOW? China's Xiaoxhai Tiankeng is the deepest sinkhole in the world at 660 metres

THE MENACE BENEATH FLORIDA

This [illegible]-metre deep sinkhole opened up beneath homes in Lake City in 2005 forcing evacuations

1 UNDERGROUND CAVES
As the limestone dissolves, pores and cracks appear, allowing more water in. This process hollows out the rock beneath, creating a large network of underground cavities. The land surface forms a bridge above these voids, and when it can no longer support its own weight it collapses in on itself, forming a sinkhole.

2 ROCK EROSION
The majority of sinkholes in Florida are caused by a layer of limestone rock lying beneath the soil across the entire state. This layer is extremely soluble, and acidic rainwater seeps through the soil until it reaches the limestone, eroding it over time.

3 UNPREDICTABLE HAZARD
It is difficult to predict when a sinkhole might open up due to numerous factors. Different soluble rock types behave differently and water can have varying degrees of acidity. This sinkhole opened up suddenly, and local authorities blamed large amounts of surface water dumped there at once by a hurricane.

4 WATER POOLS
Rain water pools at the bottom of a sinkhole, forming a shallow acidic pond of sorts that hastens the dissolution of the limestone below.

HISTORY

INCREDIBLE D-DAY INVENTIONS

How daring innovations allowed the Allies to land on the beaches of Normandy in 1944

WORDS AILSA HARVEY

It's been 80 years since D-Day, the day on which the Allied forces of World War II invaded the beaches of Normandy, France, as part of Operation Overlord. On 6 June 1944, more than 156,000 Allied soldiers fought the Nazis occupying the area, leading to the end of the German occupation of France and paving the way for the Allies' victory in Europe.

The innovative technology that was invented during the buildup to D-Day contributed massively to the effectiveness of the landings. From mathematical machines that provided crucial pre-attack information to the silent arrival of troops and vehicles that could neutralise Germany's defences, the D-Day landings were very strategically planned.

Specialised vehicles adopted new technological add-ons, such as the carpet-laying tank. This vehicle was deployed first onto the sandy beaches to lay down reinforced matting onto the soft sand, creating a surface that other vehicles could move easily across.

Planning for D-Day began in December 1941. Millions of men and women were trained and new equipment produced. The result was a well-executed plan, backed up by new technologies, that caught the German army off guard.

Tanks were deployed early, as their tracks could move across sand

Arriving by sea, Allied forces stormed the beaches

TIDE-PREDICTING MACHINE

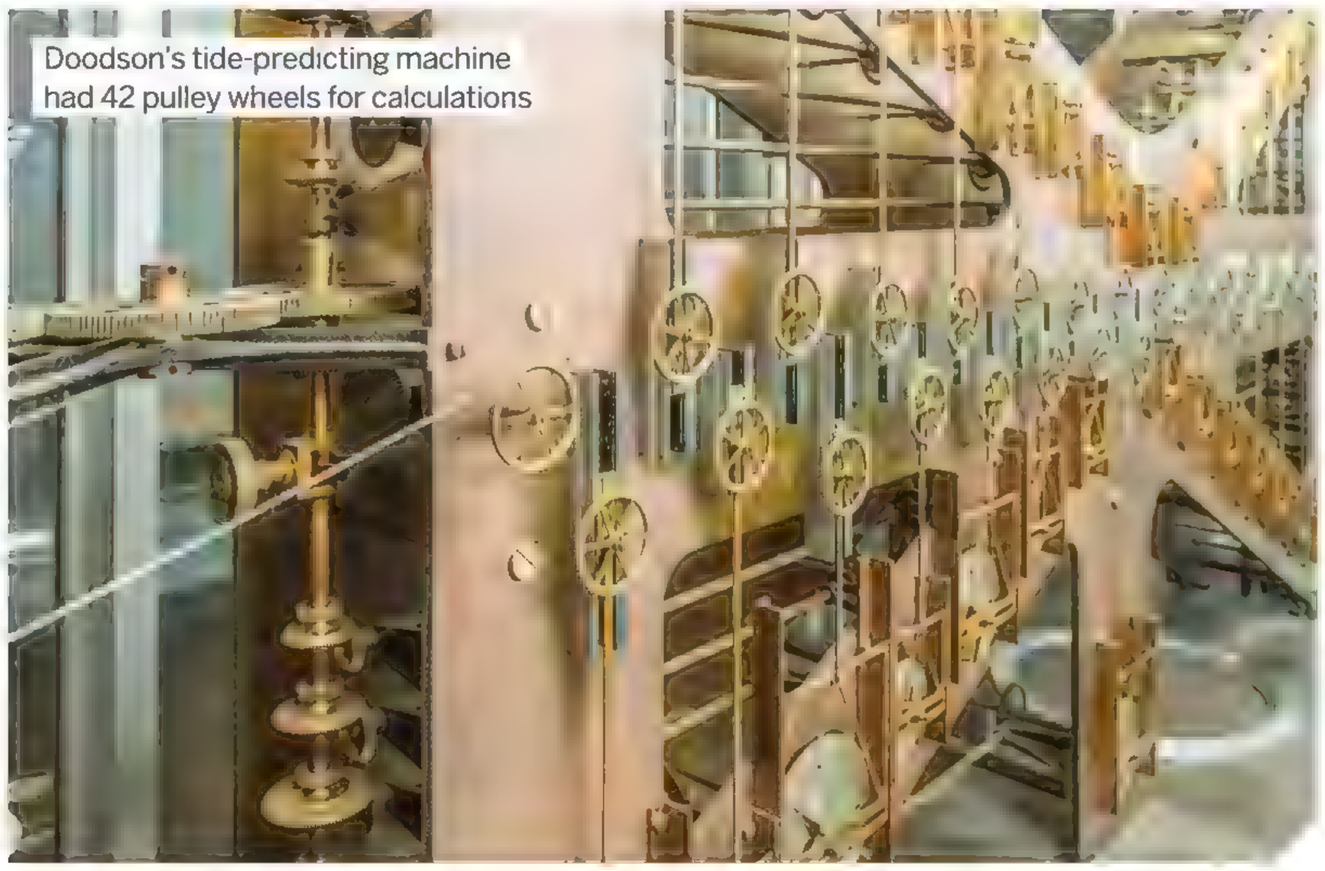
This device helped the Allies plan a low-tide invasion, when German defence obstacles were exposed

The beaches at Normandy were covered in explosive obstacles by the Germans. They believed that the Allies would attack at high tide, when they could sail all the way to land, with less beach to cross while under fire. However, the Allies spotted the underwater traps from the air during low tide and planned to invade when they were exposed instead. To launch their invasion as efficiently as possible, the Allied troops needed to know the precise timings of the tide, including the exact time of low tide for the day of the attack and the speed that the tide would rise.

To calculate the tides, British mathematician Arthur Thomas Doodson used two tide-predicting machines before inventing his own. The machines he used were the Kelvin machine, designed by Sir William Thomson, and the Edward Roberts-designed machine. Tide-predicting machines used interconnected gears, each representing different gravitational forces of the Moon, Sun and the oceans. They moved at different rates based on the data inputted. By turning the knobs to adjust the settings to different times, the positions of the Sun and Moon were calculated and the tide heights deciphered. These mechanical calculators were vital tools in planning the D-Day landing during low tide, as Doodson predicted.

Did you know?

Around 4,415 Allied soldiers died during D-Day



Doodson's tide-predicting machine had 42 pulley wheels for calculations

One of Hobart's swimming Duplex Drive tanks entering the water

HOBART'S FUNNIES

Swimming tanks and tanks that breathed fire

The Allied forces' flame-throwing Churchill Crocodile tanks had a very unusual appearance. Crocodile tanks had their main guns replaced with flamethrowers, which more effectively destroyed obstacles and caused enemy troops to panic and surrender. The vehicles were made especially for the Normandy landings and were designed by British engineer Major-General Percy Hobart. Hobart was known for his novel ideas on warfare. He promoted the idea of using tanks as an attacking force, rather than as slow, defensive vehicles. Hobart combined new and existing technologies suited to assaulting the defence obstacles that scattered the shore. Other varieties included the swimming Duplex Drive (DD) and the Crab mine-clearing tank.

The DD tanks could float on water due to their buoyant waterproof canvas and engine-powered propellers. Meanwhile, the Sherman Crab tanks were fitted with a rotating drum at the front of the vehicle with chains attached. As the drum spun around, the chains would strike the ground, detonating any mines in its path and clearing the way for the troops behind it. D-Day was the first time that each of these tanks had been used in combat.

Horsa gliders were initially towed by powered aircraft

AIR ASSISTANCE

Gliding into the fray

Gliders are planes that can travel through the air unpowered and were hugely beneficial in transporting troops and supplies to Normandy during the landings. Those invented for use in World War II were called Airspeed Horsa gliders and were some of the largest used during the war, with a length over 20 metres and a 27-metre wingspan. Each one could carry 28 soldiers or one jeep and fewer troops. Six Horsa gliders were used in the D-Day landings, each made of mostly wood and fabric. Keeping the frame lightweight meant that they could be packed with supplies without impeding their flying ability.

DID YOU KNOW? D-Day was originally planned for 5 June, but the weather was bad that day

SPECIALISED LANDING CRAFT

1,500 Higgins boats were deployed, designed to quickly release troops onto French shores

2 BOW RAMP WINCH
Crew members turned this winch to release the rope and drop the ramp.

3 MACHINE GUNS
To defend the boat and those on board, Higgins boats were armed with two machine guns.

4 COXSWAIN
This leading crew member was responsible for boat navigation and safety.

7 THREE ROLES
The crew responsible for running the boat and delivering troops were the coxswain, engineer and crewman.

8 MAXIMUM CARGO
Either 3,600 kilograms of cargo, 36 fully equipped soldiers or one jeep and 12 soldiers could travel on each boat.

6 CHEAP AND SIMPLE
Vessels were built with wood and steel plates in order to construct hundreds with ease.

5 ENGINE COMPARTMENT
The boats reached 14 miles per hour using 225-horsepower Gray Marine diesel or 250-horsepower Hall-Scott gasoline engines.

"Innovative technology contributed massively to the effectiveness of the landings"

CULIN'S CUTTERS

These tanks had tusks to cut through obstacles

Soon after the D-Day landings, tanks faced new obstacles that were of a more natural kind. Dense hedgerows made it difficult for vehicles to advance over the land in Normandy. Those that could cross over the hedgerows often tilted upwards, exposing their less armoured underside to the enemy. After witnessing this difficulty, Curtis G. Culin of the US military built hedge cutters onto tanks. Culin picked up the steel spikes from dismantled German defence obstacles called 'hedgehogs', welded them together and attached the pieces to the front of the tanks, like teeth or tusks, so that they could cut through the hedges and break them up.

This close up of the front of a tank shows how the hedgehog metal was used to make hedge-cutting extensions

PLOTTING THE PIPES

Follow the route of D-Day fuel across the Channel and along pipelines on the French mainland

5 STANLOW AND MISTERTON
The lead-based rubber was produced and pipeline parts assembled here.

6 AVONMOUTH, ENGLAND
More southerly locations were used to ready pipelines for their assembly under the ocean and load them onto ships.

3 DUNGENESS, ENGLAND
The Pluto hub at Dungeness was disguised as a standard coastal industrial site. Natural-coloured nets were also used to camouflage buildings.

500-MILE PIPELINE

279-MILE PIPELINE

2 CHERBOURG, FRANCE
Cherbourg had an existing deep-water port that Pluto's pipelines could connect to.

4 AMBLETEUSE, FRANCE
Ambleteuse, near Calais, is one of the closest points of the French coast to England.

7 EMMERICH AND MAINZ, GERMANY
Fuel was transported to these locations along the German border as direct routes for the Allies to cross over the Rhine and into Germany.

1 SHANKLIN CHINE, ENGLAND
This location on the Isle of Wight is closer to France than the UK mainland and also more secluded, increasing operation secrecy.

8 LAND-BASED PIPELINES
Some similarly designed pipelines were manufactured to transport fuel over land to crucial areas of attack.

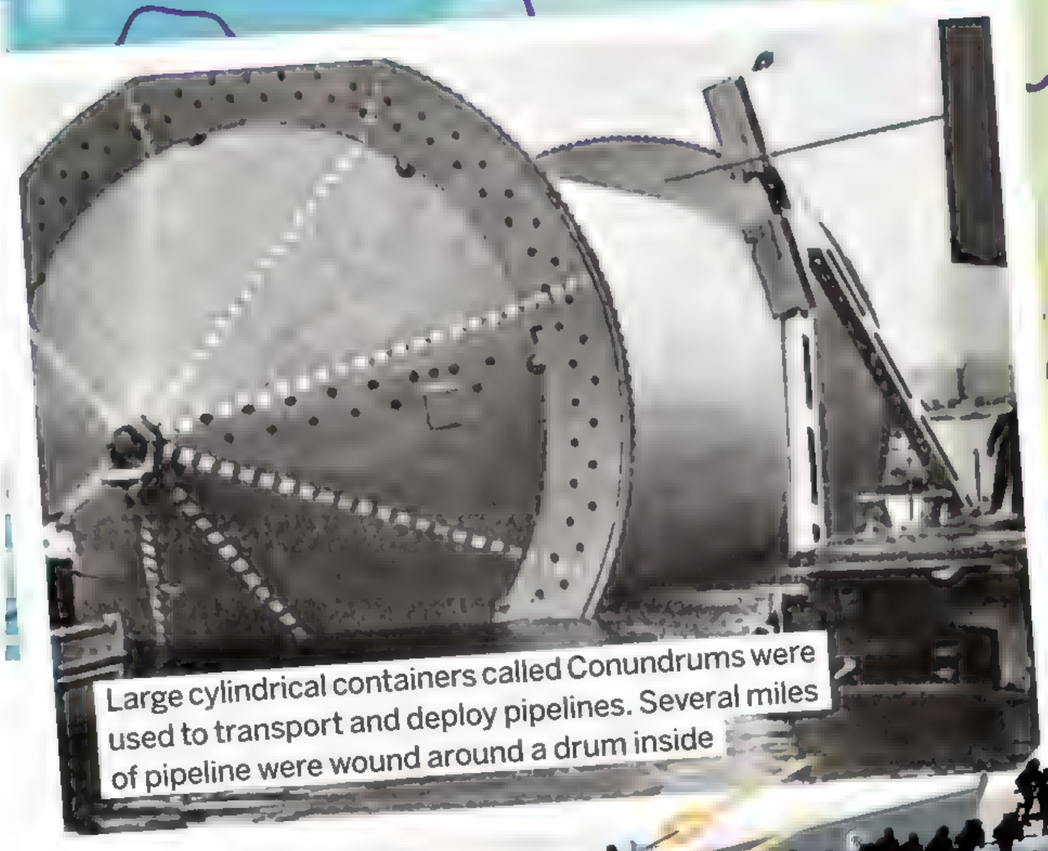
STANLOW · MISTERTON · ISLE OF GRAIN · AVONMOUTH · ALDERMASTON · DUNGENESS · CALAIS · GENT · ANTWERP · EINDHOVEN · EMMERICH · FRANKFURT · MAINZ · LUXEMBOURG · CHERBOURG · SAINT-LÔ · ALENÇON · PARIS · CHÂLONS-EN-CHAMPAGNE

OPERATION PLUTO

Why British engineers built pipelines under the English Channel

The main purpose of operation Pluto, which stood for PipeLine Under The Ocean, was to discreetly supply fuel for the Allied forces' aircraft and land vehicles in Normandy. Without this network of suboceanic pipes, the troops would have lost momentum in their attack every time they ran out of fuel. By keeping the tanks running continuously, German soldiers had less time to regroup and plot new defences. The pipelines themselves were made flexible and strong, consisting of a lead-based rubber that was strong enough to withstand the high pressures and forces encountered on the ocean floor. These were encased in metal to protect them from enemy attack and marine life.

Preparations for Pluto began two years before the attack, in 1942. The pumping stations that were used to move fuel through the pipelines were disguised as standard buildings, like bungalows, ice cream parlours and garages. Pluto was successful in delivering 4 million litres of fuel to France daily and nearly 700 million litres overall. This was a mammoth engineering mission which many historians credit as being a crucial factor in the successful D-Day invasion.



Large cylindrical containers called Conundrums were used to transport and deploy pipelines. Several miles of pipeline were wound around a drum inside

Did you know?
6,939 D-Day boats were deployed

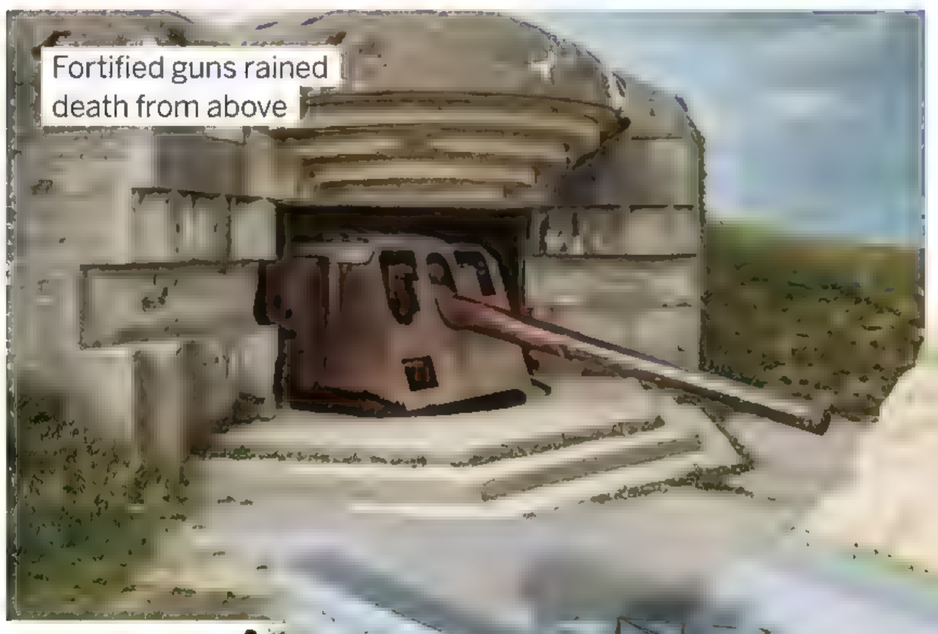
DID YOU KNOW? 7,000 tonnes of vehicles and supplies were transported over Mulberry harbours daily

MULBERRY HARBOURS

Temporary harbours kept ships safe

After the success of the D-Day invasion, British engineers quickly assembled temporary harbours off Normandy to protect any anchored ships from harsh weather. Two harbours were built, consisting of 73 hollow concrete blocks in total. At the ends of these floating blocks were floating ramps for direct access onto land. The harbours were around nine metres above sea level at low tide, three metres at high tide and around a mile in length. Beyond the harbours, the Allies sank lines of ships as further protective barriers. Large, watertight structures called caissons were sunk into the seabed to serve as foundations, keeping the floating harbours stable. All the preconstructed pieces were carried across the Channel by tugboats, and the harbours were built and operational within 12 days. One of the two harbours was successful, delivering more than 2.5 million troops to France in the ten months following D-Day. The other Mulberry harbour was destroyed by a storm soon after being erected.

A D-Day tank being driven over a Mulberry harbour



Fortified guns rained death from above

D-DAY DEFENCE

How did the Allies tackle the fortified German defences?

1 HEDGEHOGS

These consisted of two-metre-long pointy interlocking steel beams. They were positioned close together to form walls.

ALLIED SOLUTION: RHINO TANKS

Allied forces adapted tanks to add a device called a 'rhino' onto the front. These were metal frames that worked like ploughs to clear the path of hedgehogs.

2 LOG RAMPS

Log posts were arranged so that they pointed towards the sea. Mounted onto these logs were mines that exploded upon contact.

ALLIED SOLUTION: CRAB TANKS

As the tanks' rotating chains detonated the log ramp mines, thicker armour on the vehicles protected the soldiers hidden inside.

3 BELGIAN GATES

Three-metre-tall steel frames created a wall of barriers. These could interlock and be wrapped around tanks.

ALLIED SOLUTION: TANK DOZERS

Tanks with bulldozer blades were built strong enough to push and dislodge Belgian gates. With enough force, the vehicles pushed them apart and stopped them interlocking.

4 BARBED WIRE WALLS

Jagged wire was attached to the top of high walls or lined on beaches to slow down the advancement of Allied forces.

ALLIED SOLUTION: BANGALORE TORPEDOES

These long, metal tubes were filled with explosives. The Allies fired the torpedoes at barbed wire installations to produce gaps in the wire.

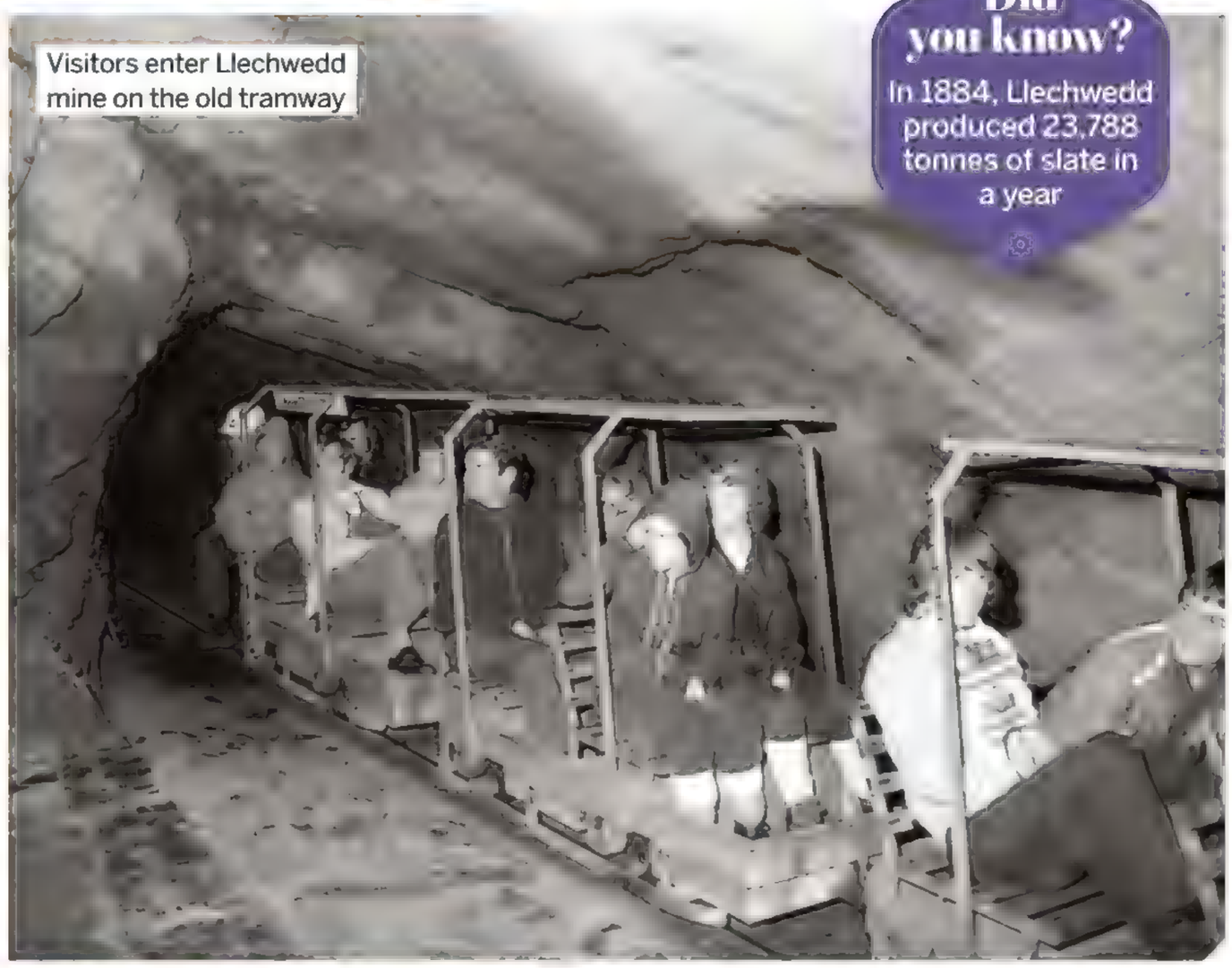
HISTORY

12 SECRET UNDERGROUND STRUCTURES

AILSA HARVEY

Discover the hidden worlds carved out of the ground across history

DID YOU KNOW? Petra is also known as the Rose City due to the colour the sandstone appears at sunset and sunrise



Visitors enter Llechwedd mine on the old tramway

Did you know?

In 1884, Llechwedd produced 23,788 tonnes of slate in a year

Petra covers an area the size of 50,000 footballs fields

DEEP MINE RAILWAY

To reach Llechwedd Deep Mine – over 150 metres beneath the rolling mountains of North Wales – you must travel on Europe's steepest cable railway. North Wales has been a slate-quarrying site for over 1,800 years; between 1846 and the 1980s, miners collected slate in this mountain pit, providing the roofs of buildings in the expanding towns and cities of the Industrial Revolution.

Miners spent long, bleak hours beneath the ground in Llechwedd's dark network of narrow tunnels and 250 quarry chambers. Its Deep Mine Railway opened in 1979, and it carries passengers down to the chambers at a gradient of 30 degrees. Visitors embark on this journey to explore the historic site. The steep passenger funicular is a high-tech replacement of the original transportation method used by miners. Workers of Llechwedd had to climb down ladders to reach the slate. From 1972 they were hauled on carriages through a newly built 61-centimetre-wide tramway by battery-powered electric vehicles.

CAPITAL CITY CARVED FROM ROCK

Between 400 BCE and 106 CE, Petra in Jordan was the capital of the Nabataean Kingdom. The Nabataeans were an ancient Arabic tribe, 20,000 of whom lived in the cliff-carved city of Petra. Inside this sandstone metropolis is a hidden maze of monuments, tombs and intricate dwellings. Historians believe that only around 15 per cent of Petra has been uncovered by archaeologists so far, while 85 per cent of the city's contents remain a mystery, their secrets still buried deep underground.

The Petra community thrived, sheltered by the desert cliffs and situated along a main trade route between Arabia, Egypt and the Mediterranean Sea. Channels were carved into the city's walls to supply water to all corners of the city, while extra water was collected in cisterns to serve the Nabataeans during the drier seasons. In 363 CE the creatively carved city was largely destroyed by an earthquake. Many of the chambers were ruined, and the true extent of the city was lost in the sandstone for hundreds of years.

INSIDE TURKEY'S ANCIENT CITY

For 2,000 years, Derinkuyu was an active subterranean city, inhabited by 20,000 people and built over 85 metres into the earth

7 INCOMING SUPPLIES

The settlement was used by various groups – Hittites, Phrygians and Christians – who hid from enemy armies. They would stock up on supplies during periods of safety.

1 KEEPING CATTLE

Cattle were kept in stables near the surface so that their toxic waste gases could escape the chambers easily.

10 WASTE REMOVAL

Any waste produced in the ancient city was stored in pots and disposed of above the ground when possible.

1 WORSHIP IN THE EARTH

The church in Derinkuyu was one of the larger chambers. The long room had extensions to make it cross-shaped.

3 WATER COLLECTION

An underground river flowed underneath Derinkuyu. Deep wells were built throughout the city to scoop up fresh water.

5 STORAGE SECTION

Large chambers throughout the city held the city's essential goods and materials, including dry food, tools and machines such as olive oil presses.

DID YOU KNOW? Derinkuyu translates to 'deep well' and is named after the water collection systems built into the city

8 BAPTISM POOL
Historians uncovered what appeared to be a baptism pool connected to the main worship chamber.

9 CHIMNEYS
Smoke produced by cooking or shaping metal tools was released from central chimneys.

11 VENTILATION SHAFTS
Over 50 ventilation shafts prevented suffocation and were used for communication between levels.

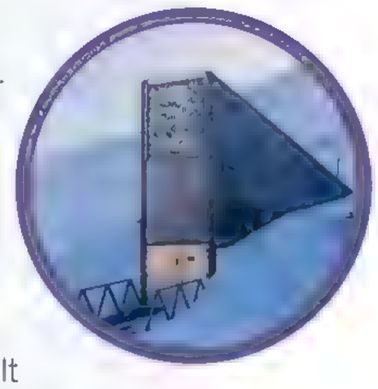
6 LIVING AREAS
The chambers covered an area of 172 square miles, with bedrooms, kitchens and bathrooms making up the living areas.

Did you know?
Stone doors in Derinkuyu weighed 500 kilograms

2 SAFETY STONES
1.5-metre-wide circular stone doors were rolled aside to open doorways. These could only be opened from the inside to prevent intrusion.

5 FACTS BUNKERS OF THE WORLD

1 SVALBARD SEED VAULT, NORWAY
This doomsday bunker is located on an island between Norway and the North Pole. Safely locked away inside are millions of seeds from 930,000 different crops. In the event of a global disaster, the vault ensures the plant species' survival to revive the planet's food supply.



2 GREENBRIER BUNKER, US
In 1955, the 34th US president, Dwight D. Eisenhower, ordered a bunker to be built below the Greenbrier Resort in West Virginia to house 535 members of Congress in the event of a nuclear strike.

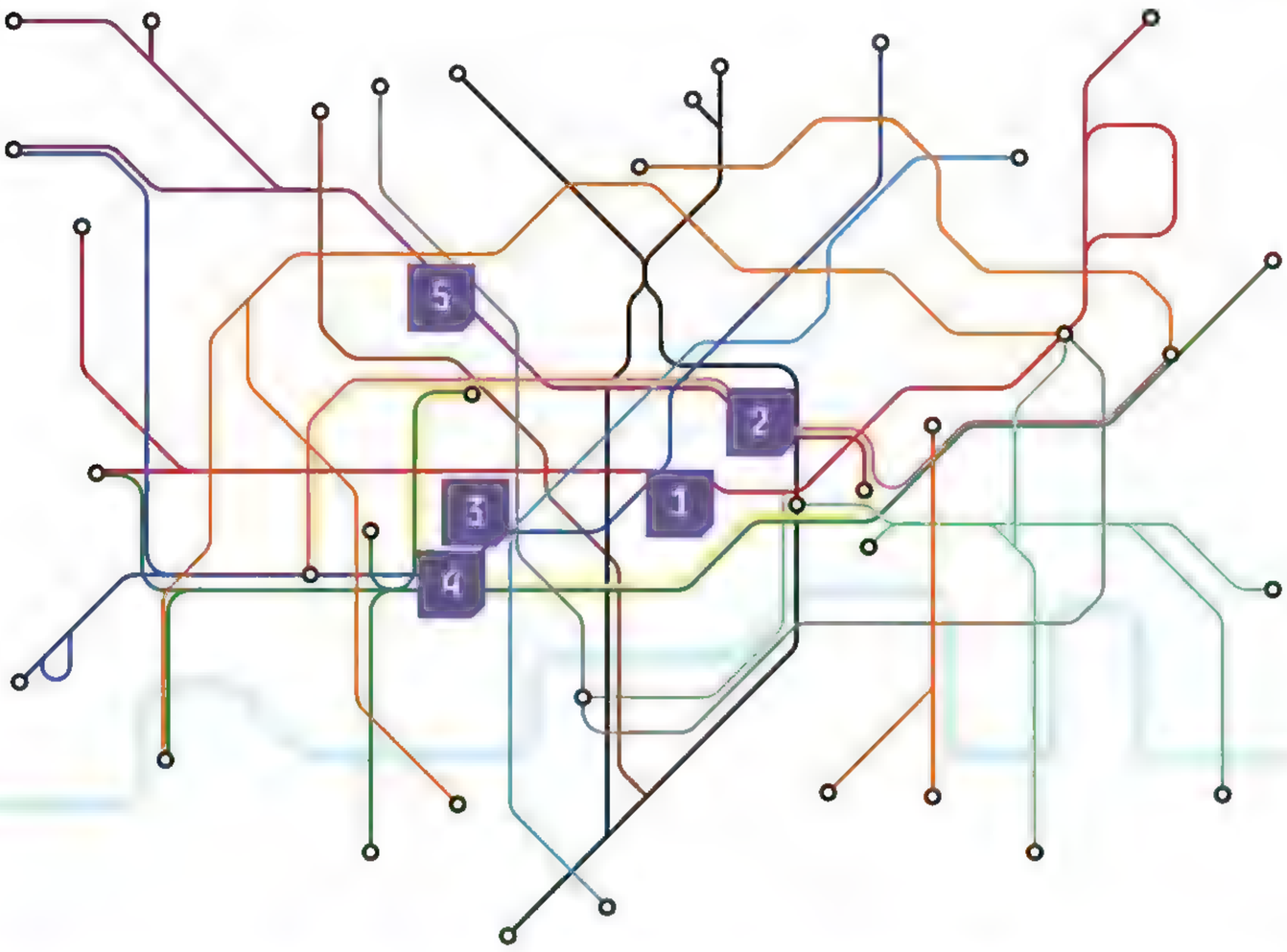
3 BUNKER-42, RUSSIA
This nuclear strike shelter was designed for Soviet leader Joseph Stalin and lies 50 metres under Moscow. It was finished in 1956.

4 BURLINGTON BUNKER, ENGLAND
Beneath the market town of Corsham, Wiltshire, is a bomb, radiation and poison gas-proof city. It was built for 4,000 government members to live in in an emergency during the Cold War.

5 HOSPITAL IN THE ROCK, HUNGARY
An underground World War II hospital in Budapest was established in a natural cave in 1944. It was connected to St John's hospital by a secret passageway to access supplies and was one of the only safe spaces for an X-ray or operation during periods of bombing.

GHOST STATIONS OF THE LONDON UNDERGROUND

What became of these failed and abandoned platforms?



1 ALDWYCH

From 1907 to 1994, this station was part of the Piccadilly Line, but was closed when the number of passengers alighting here dropped. During the Blitz the station provided shelter to Londoners.

2 CITY ROAD

In 1922, City Road station was shut after 21 years running. Some of the heat produced by the underground tunnel is now used in a new energy centre at the station to heat surrounding homes.

3 DOWN STREET

Down Street station closed down in the 1930s and went on to house Winston Churchill during the World War II Blitz. The secret government headquarters was nicknamed The Burrow.

4 BROMPTON ROAD

This station was built too close to other stations on the Piccadilly Line, and was abandoned in 1934 after 28 years of service. It was later used as the government's secret command centre.

5 SWISS COTTAGE

This Metropolitan Line station opened in 1868, but just a few days later there was a head-on collision of two trains due to there being a single track. A new, deeper tunnel was built, but this ended up replacing the original line.

The Salt Cathedral of Zipaquirá is a Roman Catholic church

ZIPAQUIRÁ'S SALT CATHEDRAL

The city of Zipaquirá in central Colombia is home to a large salt deposit, making it a popular salt-mining location since around the 5th century BCE. The deposit formed 70 million years ago when an inland sea dried out and became buried by layers of earth and mud. 40 per cent of the country's salt exports still stem from Zipaquirá today. Perhaps one of the most mesmerising tourist attractions in the area is the mine's Salt Cathedral, which was built so miners had a place dedicated to reflection and prayer. This was essential when engaging in such a dangerous occupation as salt mining. Many prayer spaces were carved over the centuries, but the existing cathedral was opened in 1995. The cathedral is carved from 250,000 tonnes of salt and can be found 190 metres underground. Before entering the cathedral, visitors pass 14 salt chapels.

The ambient temperature in Naours quarry is 9.5 degrees Celsius

FRENCH QUARRY REFUGE

Slightly east of Naours village in northern France, a hiding place is concealed beneath the soft, woodland-covered limestone rock. The secret city was first carved by Romans in the 3rd century CE, and the end result was a matrix of 300 rooms and 28 galleries over 22 metres below the ground that 3,000 people could call home. The subterranean space had initially been used as a quarry, and later a city with town squares, bakeries and three chapels. During World War I, Allied forces discovered the space and used it as a hiding place. The same occurred in World War II when the Nazis claimed it. The sneaky engineering of the quarry made it an ideal hiding place: all chimneys were directed through cottages and other overground structures so that its existence couldn't be easily detected.

DID YOU KNOW? The Zipaquirá salt mine has an average temperature of 14 degrees Celsius

THE CU CHI TUNNELS

In the Vietnam War, Viet Cong troops dug these tunnels as safe routes during combat

1 BOOBY TRAPS
Punji bear traps were positioned near the Cu Chi tunnels. When the opposing American and South Vietnamese forces stepped on the traps, the floor would fall through and they would impale their feet on large spikes.

2 SMOKE VENT
Vents from the tunnels' kitchens were directed towards long grasses and the bases of trees to keep their location concealed.

3 WATER WELLS
Vertical holes were dug until water was reached for drinking. Wells were built in these holes to collect water regularly and easily.

4 STOLEN GOODS
Any clothes or weapons left above ground by American soldiers were taken by the Viet Cong. The clothes prevented enemy sniffer dogs from finding them.

5 LIVING AREA
Some of the hammocks in the living chambers were made using American parachutes.

6 MAKESHIFT HOSPITAL
The wounded were treated below ground level to prevent enemy forces reaching the most vulnerable.

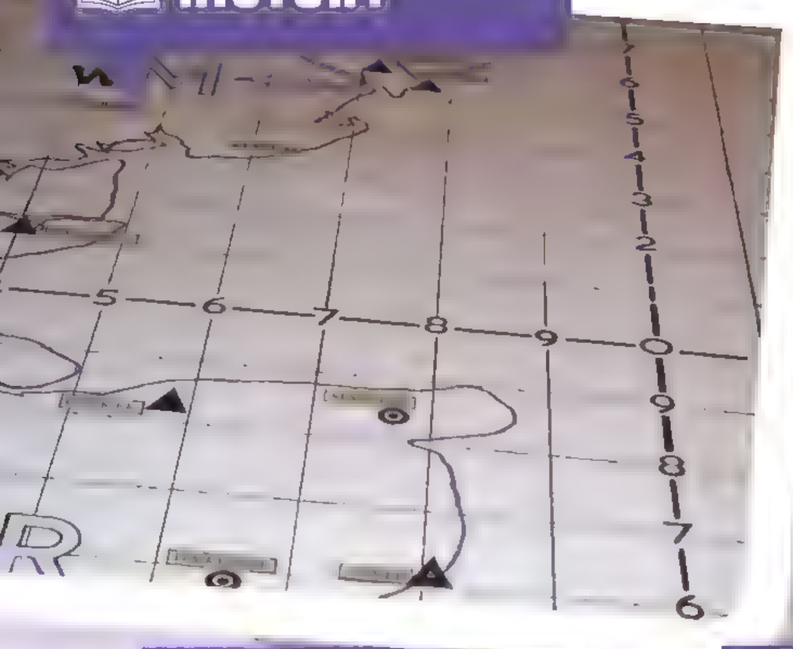
7 MEETING ROOM
Mission plans were devised by officers in dedicated meeting rooms.

8 AMMUNITION STORAGE
Ammunition was stockpiled and stored in a lower level.

9 TUNNEL RATS
American soldiers with small frames would be tasked with breaking into the narrow, hand-dug tunnels. Booby traps were dispersed for these intruders, who were nicknamed tunnel rats.

Did you know?
Bicycle electricity generators were used in some Cu Chi tunnels

HISTORY



HOW RADAR WAS INVENTED

WORDS **SCOTT DUTFIELD**

The scientific discoveries and mechanical milestones that led to the creation of one of the world's most revolutionary technologies

FINDING RADIO WAVES

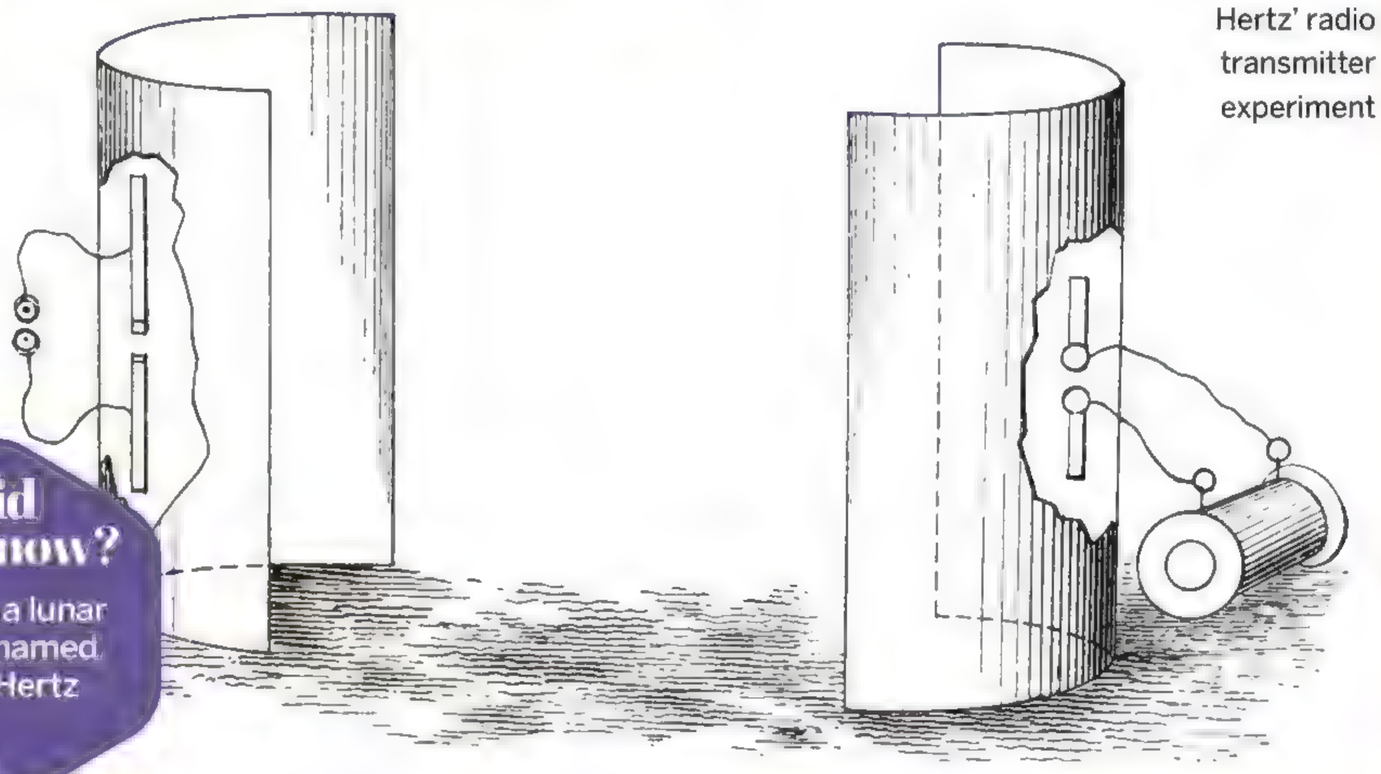
1865 In the late 1800s, German physicist Heinrich Hertz made a discovery that would change the world forever. Before Hertz' discovery, Scottish physicist James Clerk Maxwell had predicted the existence of electromagnetic radiation in 1865 in his paper *A Dynamical Theory of the Electromagnetic Field*, in which he described electric and magnetic fields moving in waves at equal speeds.

To put Maxwell's theory to the test, Hertz set up a simple home experiment to produce electromagnetic waves. Hertz used an induction coil, a type of electrical transformer, and a Leyden jar as the first capacitor to create an electrical current. The induction coil and Leyden jar were then connected to a pair of copper wires attached to two metal plates. Along each wire and sitting between the metal plates were two metal spheres. A short gap of air, called a spark gap, was left between the two spheres.

When a current was passed through the copper wire, the air in the spark gap became ionised and generated an electrical spark that jumped between the two spheres. Along with the spark, Hertz discovered that the predicted electromagnetic waves had also been released by using a receiver made from a metal loop with a similar spark gap. When the waves reached the loop, another spark was generated in the receiver's spark gap. This signified the existence of electromagnetic waves, which at the time became known as Hertzian waves, later renamed radio waves.

"Hertz discovered that electromagnetic waves had also been released"

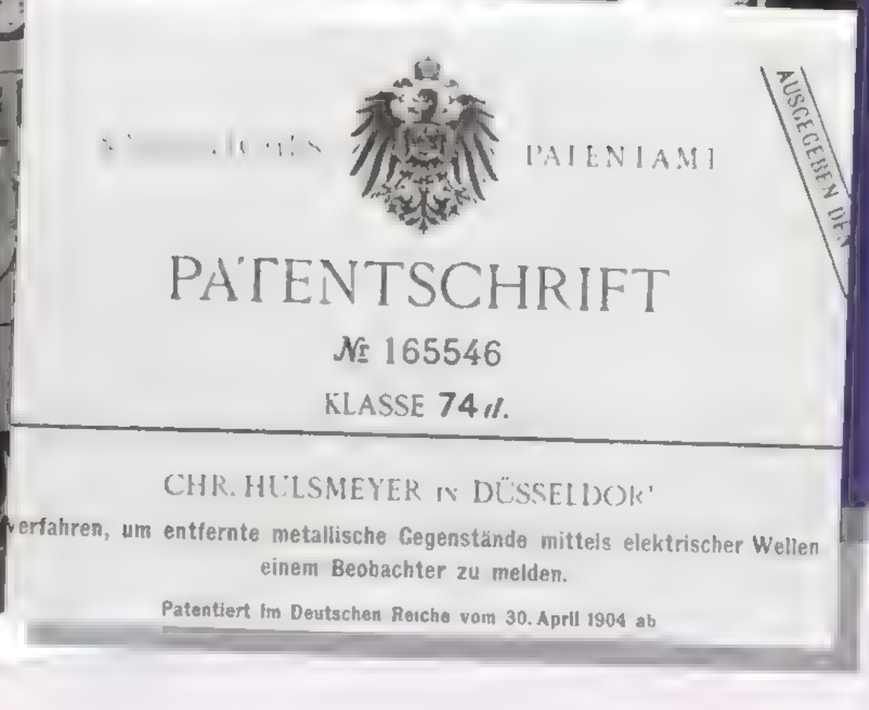
After his discovery, Hertz went on to teach as a professor of physics at the University of Bonn, Germany



An illustration of Hertz' radio transmitter experiment

Did you know?

There's a lunar crater named after Hertz



PATENTSCHRIFT

№ 165546

KLASSE 74 d.

CHR. HÜLSMEYER IN DÜSSELDORF

Verfahren, um entfernte metallische Gegenstände mittels elektrischer Wellen einem Beobachter zu melden.

Patentiert im Deutschen Reiche vom 30. April 1904 ab

THE FIRST 'TELEMOBILOSCOPE'

1903 Armed with the knowledge of radio waves and how to find them, German inventor Christian Hülsmeyer created the first device that used radio waves to detect an object's distance and position.

In 1903, Hülsmeyer patented the 'telemobiloscope', a transmitter-receiver system that could detect the presence of large metallic objects such as ships. The telemobiloscope used two spark gaps and an induction coil to emit a radio frequency. The radio waves were directed using an antenna that could be moved 360 degrees. The returning radio waves were received by a circular antenna that was connected to a device called a 'coherer'. This was a glass tube packed with metal filings. When a current was passed through the tube, these filings clumped together, completing an electrical circuit and ringing an attached bell.

Hülsmeyer intended for the device to be used as a way of preventing ships from colliding with one another. When the telemobiloscope was pointing towards a river, the emitted radio waves would bounce off the metal hulls of passing ships and return to the antenna, causing the bell to ring. But although Hülsmeyer's invention could detect the presence of a ship, it couldn't be used to measure its distance from the transmitter.

A pair of acoustic mirrors in Kent, UK

ACOUSTIC MIRRORS

1916 While early radar technology was still finding its feet, much of Europe had been catapulted into World War I. The need for a technology that could detect advancing enemy aircraft had never been so crucial. As the precursor to radar, the British Armed Forces invested in 'listening ears' known as acoustic mirrors.

Invented by Major William Sandome Tucker, the director of acoustical research for the Air Force, acoustic mirrors were giant concrete half-spheres used to pick up the sound waves of flying engines, amplify them and bounce them to a microphone. Like electromagnetic waves, sound waves can be reflected and focused to a partial point. The shape of the mirrors caused the sound waves to reflect off the back of the half-sphere and hit the microphone situated in its centre. A vigilant soldier would then sound the alarm when the mirrors tuned in to the sound of enemy threats in the sky.

Acoustic mirrors could give the military a 15-minute head start to prepare for an oncoming attack. However, on the precipice of a second world war, the acoustic mirrors that lined part of England's south coast were abandoned to give way for the very first military radar stations.

THE DAVENTRY EXPERIMENT

1935 Hülsmeyer had already proven the ability of radio waves to detect ships, but its use in detecting flying objects was yet to be seen – until British inventors Robert Watson-Watt and Arnold Wilkins conducted a pioneering experiment in Daventry, UK. Watson-Watt was head of the Radio Research Station in Slough. During his time at the station, he and Wilkins showcased how radio waves could be used to detect aircraft. In a field experiment, the pair built several posts suspending wires connected to a receiver in the back of a van. The radio waves came from BBC broadcast transmitters near Daventry. When a Handley Page Heyford bomber flew by, the field-bound receiver not only detected its flight, but its eight-mile distance. Watson-Watt and Wilkins' achievement ignited radar research in Britain, and the government approved the construction of new coastal radar stations to detect invading aircraft.

Watson-Watt experimenting with a kite and a wireless radio transmitter

BIG EARS

How acoustic mirrors picked up on enemy invasions using sound waves

1 CONCRETE MIRROR
Concave bowls of concrete formed the shape of an acoustic mirror, up to around four metres in diameter.

2 INCOMING SOUND
The sound of fighter plane engines up to 25 miles away could be picked up by acoustic mirrors.

3 REFLECTION
The concave shape of these mirrors caused incoming sound waves to reverberate and hit a microphone at the centre.

4 MICROPHONE
Sound detected in the mirror was picked up by sensitive microphones and transmitted to the headphones of their operators.

DID YOU KNOW? In 1940 the United States Navy coined the term radio detection and ranging, shortened to radar

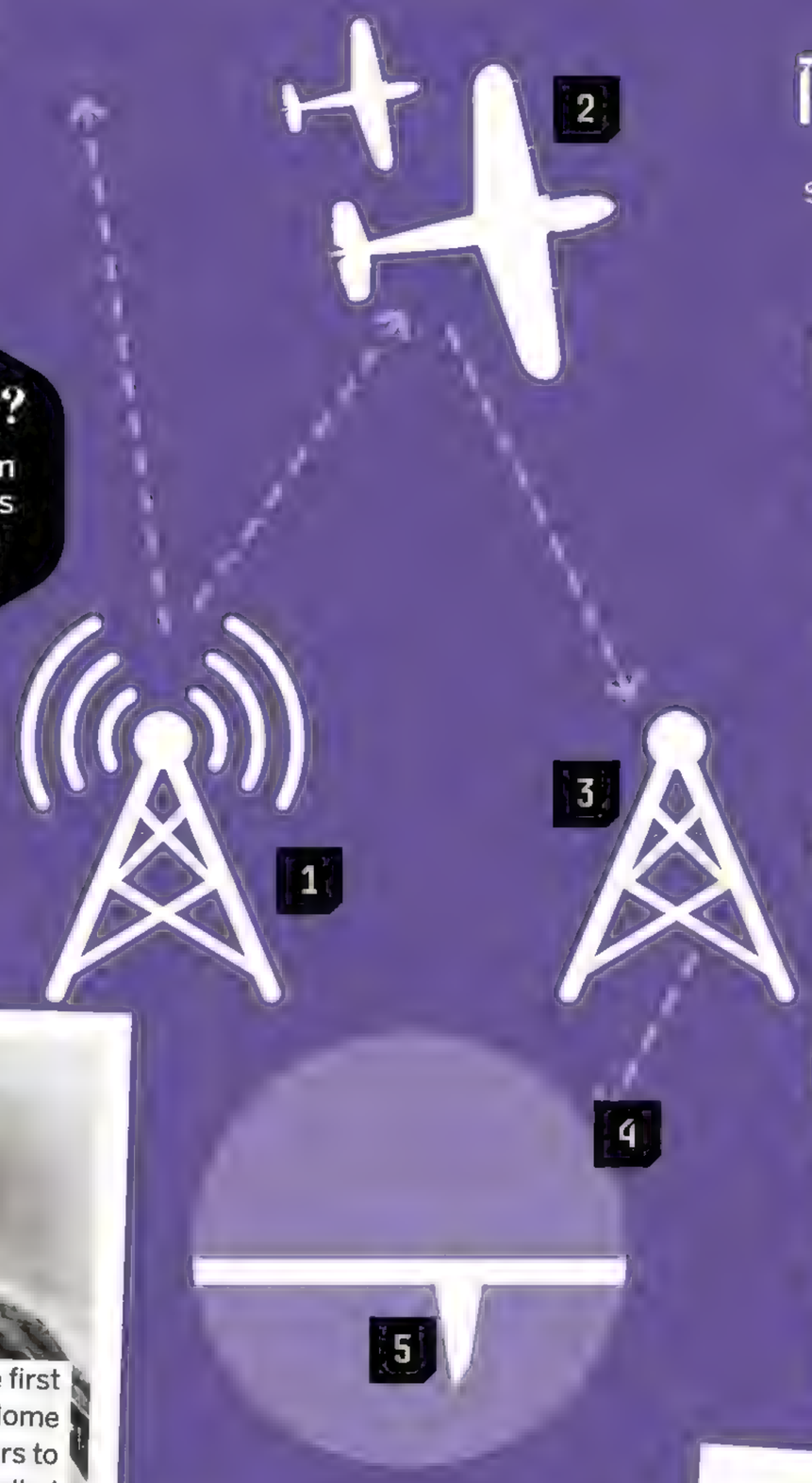
CODENAME CHAIN HOME

1935 to 1941

With word that the German military might bring 'death-ray' radio technology aboard their fighter planes to a second world war, Britain quickly constructed coastal radar stations to spot aircraft before they crossed its shores. Known under the codename 'Chain Home', it was a network of transmitter antennae and receiver stations for a giant radar system that could detect incoming aircraft from around 100 miles away. The transmitter antennae sent long pulses out into the English Channel to bounce off any incoming enemy aircraft and return to the receiver station. The encounter would then appear on a radar display, alerting the operator to the presence of the aircraft. This helped give the Royal Air Force enough time – around 20 minutes – to jump into fighter planes and face the enemy before they had the chance to reach land. By 1939 Britain had 18 Chain Home radar stations, and by the end of World War II, 53 had been constructed.

Did you know?

By 1938, Chain Home stations operated 24 hours a day



RADIO BLIPS

How the Chain Home radar system spotted enemy aircraft

1 TRANSMISSION
Pulses emitted from 110-metre transmitter towers flooded large areas of the coast of England towards continental Europe with radio waves.

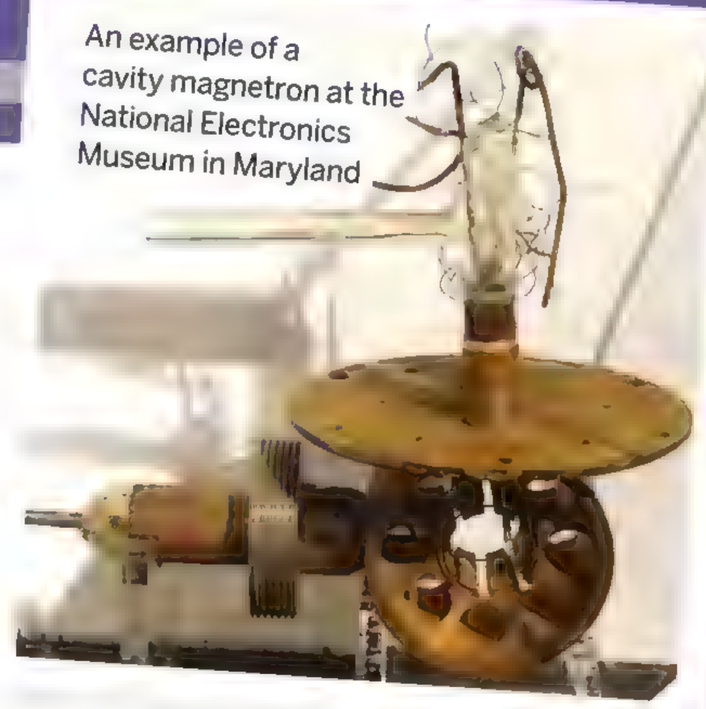
2 BOUNCED WAVES
When the radio waves hit enemy aircraft, they were reflected and bounced back towards the station.

3 RECEIVER
The radio waves were detected by receiving aerials at the Chain Home stations.

4 BLIP
When an aircraft was detected by radio waves it appeared on a display screen as a spike on a horizontal line, called a 'blip'.

5 POSITION
Operators used the position of the blip on the line, along with its size, to determine its distance and placement in the sky.

One of the first Chain Home radar towers to be installed



An example of a cavity magnetron at the National Electronics Museum in Maryland

MOVE ASIDE FOR THE MAGNETRON

1940 Although revolutionary, Chain Home wasn't without its limits, especially its range of detection. Looking for a way to extend the reach of radar, British physicists John Randall and Henry Boot of the University of Birmingham invented a new type of radar called the cavity magnetron.

The device was made from a piece of cylindrical metal with a negatively charged electrode, or cathode, running through a central hole. Surrounding the cathode was an anode – positively charged electrodes in a series of holes, or 'cavities'. When power was passed through the cathode, a magnetic field emerged around the device and electromagnetic waves radiated from the anodes. These were microwaves, which were much shorter in length than radio waves – just ten centimetres compared to the up to 13-metre wavelength of radio wave radar. For radar, transmitters that use shorter wavelengths are sensitive to detecting targets at longer ranges, and they can be produced in smaller and less expensive devices.

The cavity magnetron was small and mighty. However, Britain's manufacturing industry at the time couldn't sustain mass production of the device. Looking across the pond, Britain turned to America, which had not yet entered the war, for help. Having made the trip on a ship safely across the Atlantic, a Welsh physicist named Edward Bowen revealed the magnetron technology to the Americans. Seeing the potential for the device and its impact on military success, President Franklin D. Roosevelt approved funds to establish the Radiation Laboratory at the Massachusetts Institute of Technology (MIT) to replicate the new microwave radar. These new radars were adapted for compact units installed on aircraft or large truck-mounted devices for long-range detection.

TECHNOLOGY

FUTURE DRONES

WORDS AILSA HARVEY

DID YOU KNOW? The first US drone permit was issued by the Federal Aviation Administration in 2006

DISCOVER THE FLYING MACHINES THAT CAN DELIVER GOODS, EVACUATE INJURED SOLDIERS FROM THE BATTLEFIELD, HELP FARMERS GROW CROPS AND MORE

The de Havilland DH82B Queen Bee could be flown crewed or uncrewed

Drones are uncrewed aerial vehicles (UAVs) that can be either autonomous or remotely controlled. While many of their modern applications could have them mistaken for new inventions, drones have existed for many decades. In 1935, between World War I and II, the British Army invented a radio-controlled aircraft to be used for military target practice. The aircraft was called the de Havilland DH82B Queen Bee, but was nicknamed a 'drone' and is believed to be the first modern drone. Today, armies own fleets of drones in the tens of thousands, and they have become increasingly popular for private use too.

It wasn't until the 21st century that drones began to be used by civilians for recreational purposes, but today there are more than 885,000 drones registered in the US alone. Smaller drones with high-quality cameras began to be used in film-making, with the first drone scene in a major Hollywood film shot in 2006 for *Miami Vice*. Since then, aerial shots have become commonplace in setting movie scenes, providing new and artistic perspectives.

These same aesthetic shots can be captured by recreational drone users thanks to the invention of the smartphone. As smartphones became mass produced, the prices of accelerometers, microcontrollers and camera technology reduced, making drones more affordable over time.

Did you know?

In Europe, drone users must be 16 years old

An increase in drones comes with increased surveillance, but there are many laws in place surrounding the private use of drones. Every drone owner must register their device and display their unique drone number on the aircraft at all times. There are also laws and distance restrictions preventing flight over private and residential land to maintain privacy.

WORLD RACERS

Drone flying has been adopted as a professional sport in a tournament called the Drone Racing League (DRL). Millions of DRL fans can watch live footage straight from the drones of the world's best drone pilots through streaming platforms such as YouTube and TikTok.

They're flown at over 80 miles per hour, and competitions take place in stadiums around the world or as virtual races in simulators. In real-life races, these need to be operated in first person – as if the pilot was sitting in a cockpit. The drones have a camera that the pilot can connect to in order to watch live footage and steer. Usually, this is viewed through a headset, like a virtual-reality game.

The first amateur drone racing began in New Zealand and Australia, but as it grew in popularity, the DRL was established in 2015. This sport will once again take place at the 2025 World Games in Chengdu, China – an event it has featured in since 2022.

DRL pilots usually build their own drones for races

FAST-FLYING COURIERS

Amazon hopes to speed up its delivery times with its latest Prime Air MK30 drone

1 PARCEL PICKUP
The MK30 can carry packages up to 2.2 kilograms.

2 VERTICAL CLIMB
From Amazon's fulfilment centre launch pad, the drone climbs to 40 to 120 metres at a maximum speed of 65 miles per hour.

3 AUTONOMOUS FLIGHT
The drone's computer directs travel to the recipient in one hour or less.

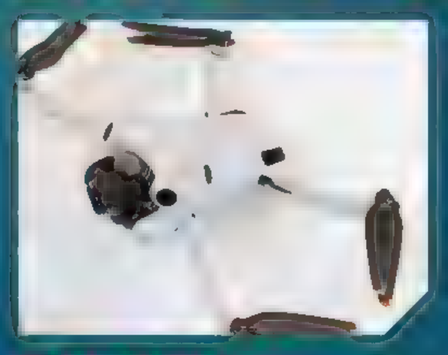
4 OBSTACLE AVOIDANCE
Built-in cameras and sensors help the drones detect obstacles and alter their altitude to avoid collisions.

5 MARKER SEARCH
The customer has to place an Amazon landing pad on the ground near their property before the drone's arrival.

6 CUSTOMER DELIVERY
When the drone sees the landing pad, it descends from just above it, opens its doors and releases the package onto the pad.

Did you know?
Amazon's delivery drone is quieter than traffic

BEST YOU CAN BUY



MOST COMPACT
With a weight of 249 grams, the DJI Mini 4 Pro is a compact drone that can maintain high-quality footage in flight. Its frame can be folded inwards to fit on the palm of your hand when not in use.

BEST CAMERA QUALITY
The DJI Mavic 3 Pro is the first consumer drone with three cameras. The drone can capture 5.1K-pixel resolution at 50 frames per second, or 4K at 120 frames per second.

MOST ACROBATIC
A first-person view (FPV) drone relays footage of what the drone 'sees' in real time. The DJI Avata 2 is one of the best consumer FPV drones with an easy acrobatic mode for manoeuvres.

AMAZING AUTOMATION
The Skydio 2+ has six 4K 200-degree cameras that help it spot obstacles all around it, enabling safe autonomous flight. Its AI-operated computer can process 1.3 trillion operations per second.

HIGH ENDURANCE
The Autel Evo Lite+ drone's battery can provide 40 minutes of flight time. Most commercial drones can only last up to 20 or 30 minutes before they need to be recharged.

DID YOU KNOW? Delivery drones have been tested in the UK, mainland Europe and Australia

"There are more than 885,000 drones registered in the US"

Amazon's MK30 Prime Air drone on display at one of its fulfilment centres in Washington, US

DRONE INTERCEPTORS

How net-firing guns collect space debris and illegal drones

1 NET-FIRING GUN
These guns can be deployed on satellites in space or fixed structures and drones on Earth.

2 TARGET
Whether the target is a rogue drone or orbiting space debris, the gun's camera tracks the target to keep the net lined up.

3 CAPTURE
When the drone comes within reach, the gun launches the net. Four weights wrap around the drone, catching it in the netting.

4 RETRIEVAL
A motor pulls the net back. For drones retrieving other drones close to Earth, this prevents the drone hitting the ground.

5 DAMAGE PREVENTION
Satellites can be retrieved and illegal drones examined as the netting captures devices without damaging them.

TEAM PERFORMERS

Drones can be used for entertainment as well as high-priority jobs. For example, to welcome in 2024, the city of Ras Al-Khaimah in the United Arab Emirates launched a spectacular light show using 1,050 drones. The eight-minute show broke the world record for its runtime and stretched 1.2 miles across the sky. The LED-lit drones moved in synchrony to form shapes, words and patterns. Drones that work together like this are called swarms. In drone shows, each drone is programmed by a computer to follow its own flight path, carefully avoiding the surrounding drones. They communicate with neighbouring drones and use proximity sensors to keep a specific distance apart. The position and LED colours change throughout the performance to depict different objects in the night sky.

Small, bright drones such as the Firefly Gen2 are used for light shows

MILITARY DRONES

BATTLEFIELD CARGO

The T-650 drone can [illegible] around 300 kg of military supplies

3 MILITARY SUPPLIES
With a maximum payload of 300 kilograms, it can deliver additional military supplies to troops during long missions.

6 FLIGHT COMPUTER
The computer processes live flight data, such as altitude and speed, as well as receiving obstacle-detection data from sensors so it can autonomously control the drone.

5 POWERFUL BATTERIES
Lithium-polymer batteries have the highest power-to-weight ratio. They can be easily and quickly replaced with charged ones between flights.

8 PROPELLER
There are four sets of stacked propellers so that if one fails or is damaged, the drone can still land safely.

1 CASEVAC
For short-range airlifts, a casualty evacuation payload can be attached to the drone.

7 DRIVETRAIN
As the propellers rotate, the drone is powered to a maximum speed of 87 miles per hour.

Engineer and helicopter pilot Chris Malloy founded the company behind the T-650, Malloy Aeronautics

A lithium-polymer battery for a commercial drone. The T-650 is powered by the same technology

DID YOU KNOW? Google launched a food drone delivery service in Australia in 2019

2 TORPEDO
An anti-submarine lightweight torpedo called Sting Ray has been tested with the drone as a payload option.

Did you know?
Racing drones can go from 0 to 90 miles per hour in one second

4 CARBON-FIBRE CHASSIS
The drone has a carbon-fibre layer, making it lightweight and long-lasting even against corrosive chemical weapons.

Even the T-650's little brother, the T-400, is capable of lifting heavy loads

NEIL APPLETON

BAE Systems' Malloy Aeronautics has developed a series of heavy-lift drones, including the T-650. The company's CEO explains the value of these drones in the military

What makes drones good for resupply missions?
In ship-to-ship resupplies, typically you would start moving things from one ship to another with an expensive helicopter. That is very much like using a sledgehammer to crack a nut. If you imagine the capability of a helicopter, it can loiter for hours, it can carry tonnage, it can do all kinds of complex electronic warfare or submarine hunting, and instead you're using it to move bags from one ship to another. That's not a good use of that platform, and it's the only solution customers have today. Our drones allow them to use a simpler and cheaper platform – from £20,000 [$25,181.95] to around £100 [$125.90] per hour.

How is the T-650 designed to work in all weather?
The drone itself has a vehicle management system that adjusts the platform to strong winds and gusts to stabilise itself. Beyond that, we've taken the platform to the desert and the Arctic, in temperatures of -20 and 40 degrees Celsius. They don't like the cold. But that doesn't mean you need a complicated system to keep them warm prior to deployment. When our platforms were deployed to the Arctic, the batteries were kept warm in a vehicle and then installed to the aircraft just before flying with no deterioration in performance. During flight, when the batteries are generating heat because they are being used, it helps compensate for the fact it's -20.

Is it safe to carry injured soldiers by drone?
Casualty evacuation is designed around the vehicle of opportunity, which means if you've got an injured soldier on a battlefield, you don't necessarily want to wait for an ambulance. You use whatever vehicle you've got in the area to get them out in that golden hour – the first hour of an injured soldier is key for survival. If you're an injured soldier, would you want to climb underneath a drone? We've had some soldiers say, "Absolutely. I'm injured, get me out of there," and other soldiers say no. There's very much a different perception among the military community on this, and what we're trying to do is stimulate that conversation.

"Technology evolves and autonomy gets better"

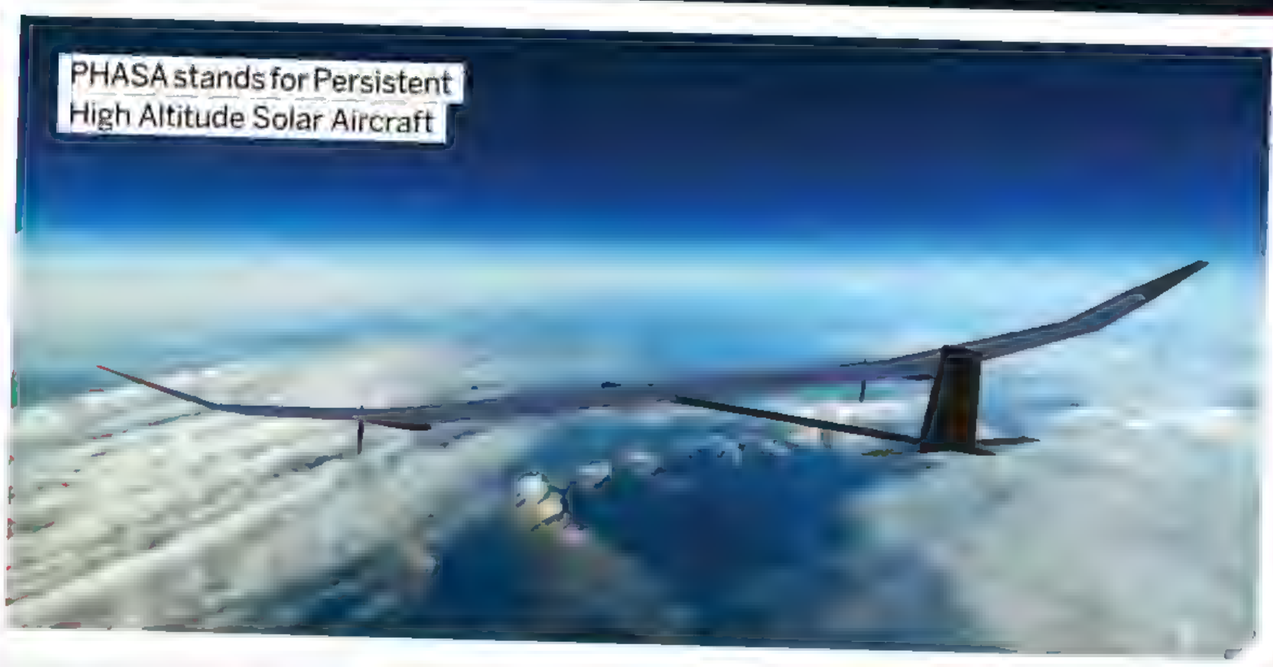
How do you see uncrewed drone technology shaping the future?
As technology evolves, autonomy gets better. In the future you could have one individual flying ten drones almost like an air-traffic controller, rather than on a one-to-one basis. And all they're doing is monitoring that the missions are taking place as designed. It's a different skill set which will reduce the burden on frontline people.

MILITARY DRONES

Concept 2 is described as a medium-sized UAS

UNCREWED ATTACKER

BAE Systems' Uncrewed Air System (UAS) Concept 2 drone has been designed to demonstrate how autonomous technology can be utilised on the battlefield for efficiency and safety. It can fly at altitudes above 12,000 metres for up to five hours at a time in order to engage fighter jets at this high altitude. With a maximum takeoff weight of 3,500 kilograms and an internal payload of 500 kilograms, the drone can launch air-to-air and air-to-ground missiles. It also allows for electronic attacks by carrying payloads that block radio signals. UAS Concept 2 has a fixed-wing design with a V-shaped tail, which requires a runway for traditional takeoff and landing and is powered by a jet engine that can reach speeds of 575 miles per hour.



PHASA stands for Persistent High Altitude Solar Aircraft

HIGH FLYER

In June 2023, BAE System's PHASA-35 drone achieved stratospheric flight by travelling at an altitude over 20,000 metres. The high-altitude aircraft can be used for long-term surveillance as it doesn't rely on jet fuel. Instead, it's powered by the Sun. PHASA-35's photovoltaic arrays power it throughout the day, as well as storing excess electrical energy in its rechargeable batteries to use during hours of darkness. Commercial aircraft fly in the troposphere, the lowest layer of Earth's atmosphere, at altitudes of around 6.2 to 8.0 miles. The stratosphere begins at around 12.4 miles, making PHASA-35's height a safer space for military surveillance.

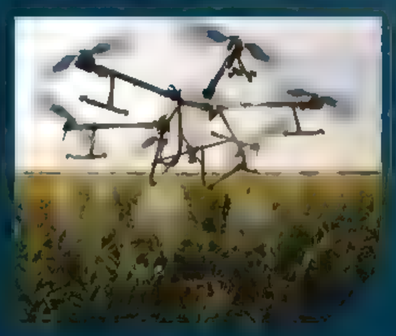
A XAG P100 on display at the DroneX exhibition 2023

FIVE FARM ROLES

There are multiple ways in which the XAG P100 drone can help farmers

1 LIVESTOCK COUNTING
High-resolution cameras can capture detailed field surveillance. With machine learning, cameras can detect specific animals.

2 PRECISION SPRAYING
The XAG P100 can target crops with pesticides with precision from an aerial position. Its droplet size is 60 to 400 micrometres.



3 FIELD MAPPING
Accurate aerial field maps can be composed using drone imagery. These are analysed to detect weeds and track crop yield and location.

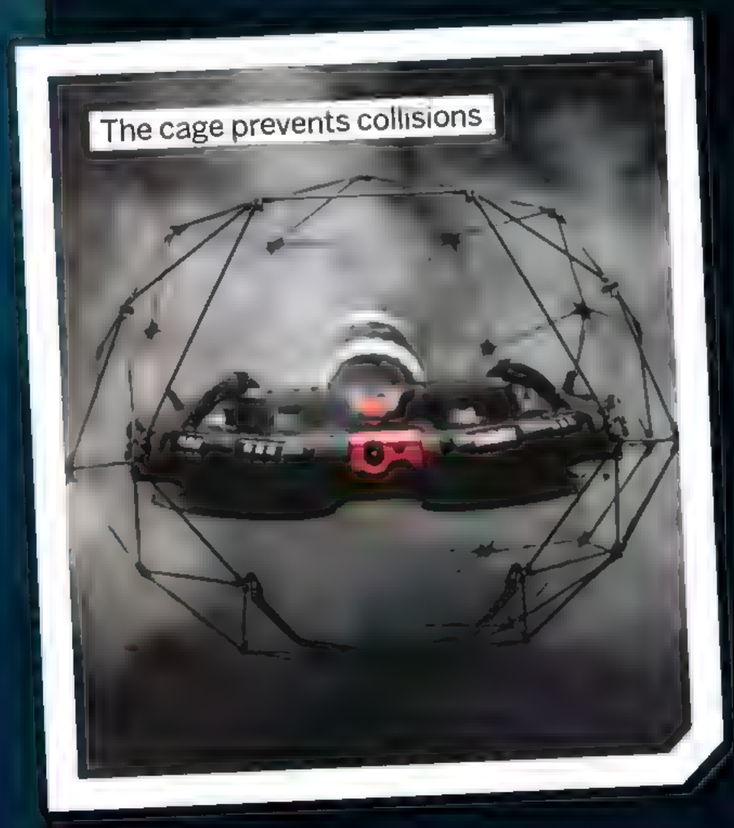
4 AUTONOMOUS PROGRAMMING
Based on the field map, the drone is programmed to follow specific routes around the farm to attend to crops.

5 DISEASE DETECTION
The drone flags any visible signs of disease, enabling farmers to locate the exact site of the affected crops before the disease spreads.

DID YOU KNOW? Lifeguards in Australia started using drones to detect sharks in 2020

INDOOR SURVEYOR

From exploring caves to mapping industrial sites, Elios 3 carries out safer inspections of enclosed spaces



1 LIDAR
Elios 3 uses a pulsed laser to map out the perimeter of enclosed spaces. This is saved as a 3D digital file.

2 RESILIENT CAGE
The drone is surrounded by a carbon-fibre cage, which is hard yet elastic, to withstand collisions.

3 THERMAL CAMERA
Heat anomalies in industrial sites can be detected with the thermal camera's data.

4 4K VISION
The front camera relays live footage to workers, covering a 180-degree field of view.

5 DISTANCE SENSORS
A time-of-flight distance sensor measures how close surrounding obstacles are so that operators can change direction and avoid collisions.

6 SMART LIGHTING
These LED panels can be operated independently to create the optimal lighting for analysing different environments and details in varying dust levels.

Did you know?
Elios 3 can produce a centimetre-accurate map

7 PROPELLER
The four propellers are replaced every ten flight hours.

8 NAVIGATION LIGHT
Coloured LED lighting is used at the rear of the drone to show the orientation of the drone and display warnings such as low battery status.

9 MOTOR
When the drone reaches a wall, it uses its reversible motors to back itself up.

"A distance sensor measures how close surrounding obstacles are"

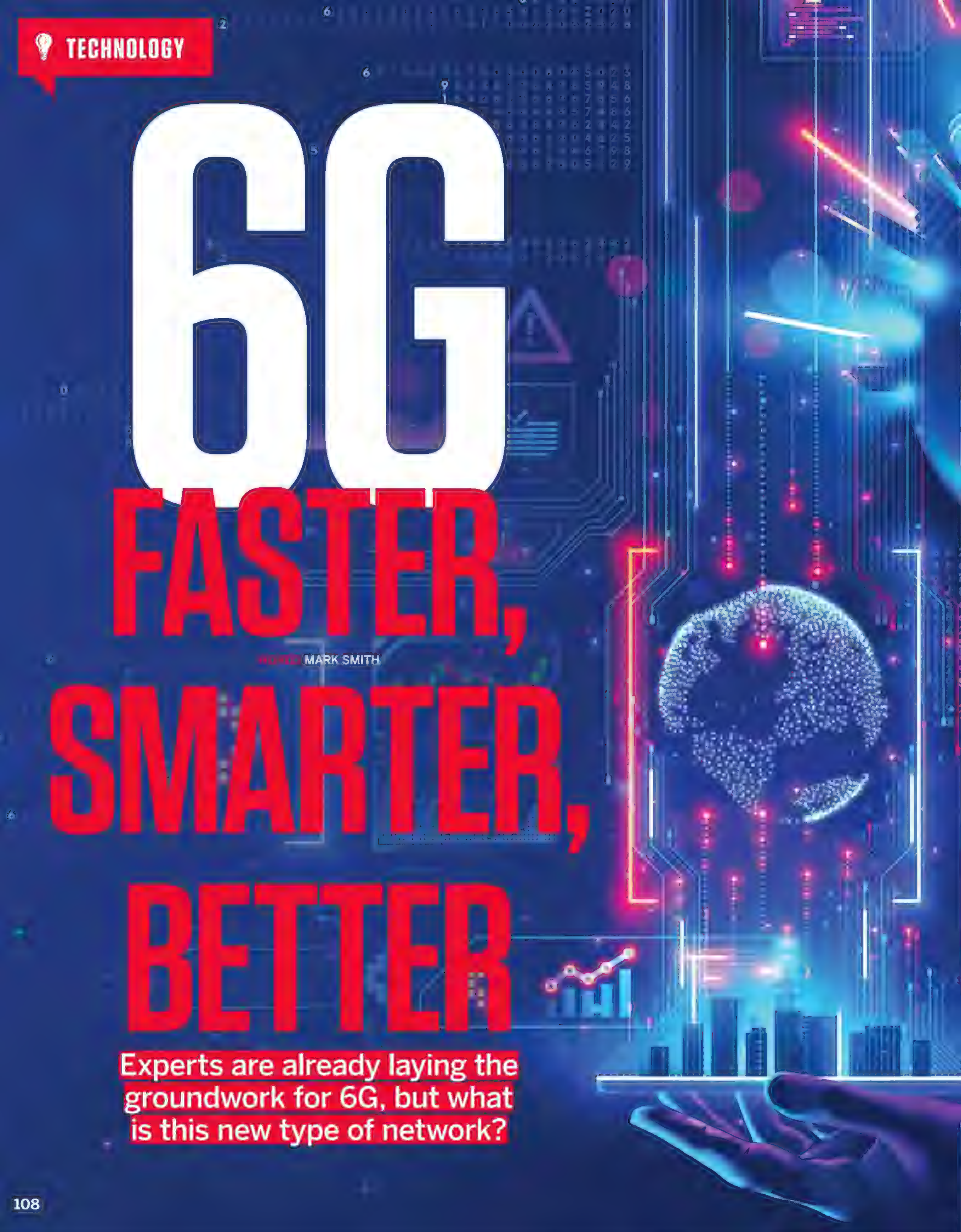
TECHNOLOGY

6G

FASTER, SMARTER, BETTER

WORDS MARK SMITH

Experts are already laying the groundwork for 6G, but what is this new type of network?



DID YOU KNOW? While smartphones will remain a key device, new human-machine interfaces will make them more convenient to use

Picture a world where you control machines with your mind, where driverless cars move through rush-hour traffic with no chance of being in a crash or where the internet is a thousand times faster than it is today. This is the promise of 6G. We've all heard of 5G, and most of us have probably already used this wireless technology to watch movies and play games, search online and do any number of other things at speeds that simply wouldn't have been possible even a few years ago. But progress never stops, and now we're entering a new era: 6G. But beneath its rather predictable name lies a technology that could change the world. So what is 6G?

The world around us is filled with an invisible web in which data from our smartphones, televisions, sensors, doorbells and pretty much every other type of smart technology communicates. The problem is that previous iterations of this invisible web – wireless networks like 4G – didn't have the bandwidth to send complex data like you'd have in, say, industrial devices. But that's changing. The 6G generation will use technology that enables it to send data at ultra-high frequencies.

Did you know?

Terahertz signals can pass through ceramics, plastic and paper

While 5G can support frequencies up to 100 gigahertz (GHz), for 6G the aim is to transfer data across waves in the hundreds of gigahertz, or terahertz (THz), ranges using technology such as edge computing, artificial intelligence and terahertz waves.

One of the goals of 6G is to support something called 'one microsecond latency'. Latency is the delay in information getting from one place to another – think of the annoying buffering when you're watching a movie on a tablet. 6G would work at one microsecond latency, which equates to one-millionth of a

Mobile World Congress visitors experiencing the Human Augmentation Platform, which allows people to communicate haptic sensations by being connected to a 6G network

A 6G smart city model at the Ericsson stand at the Mobile World Congress

second – virtually instant. The ability to send and receive data in such volume opens up a whole new era of possibilities. There have been major advances in recent years in things like artificial intelligence, smart sensors and virtual reality, but they all still largely exist in isolation from one another. The end goal is to plug them all together virtually, and that's what 6G could do. It would have the bandwidth and low latency to form a new invisible network. But instead of just games and televisions, it would be robots, cars and even chips that might one day be plugged directly into our brains to enable us to interact with devices.

Did you know?

6G peak data rates could be up to 50 times faster than 5G

Another relatively new technology that 6G will help underpin is edge. Up until now, most smart technology has been connected to a central processor operating in the virtual cloud. Sensors on roads, for example, would have to send their traffic or weather data wirelessly to the cloud for a system to crunch the numbers. But edge means those sensors can be genuinely 'smart', with all the brains they need to decipher the data at the source rather than send it wirelessly to a central cloud network. This makes things faster and reduces the possibility of signals being interrupted, vital for something like controlling a driverless car in traffic. The use of 6G could also underpin a true virtual world for the very first time, where your physical self can operate virtually – perhaps working in a virtual office with virtual representations of your real-world colleagues or studying at a distant college or school. 6G would enable you to interact virtually with objects because it could transmit the vast quantities of data needed to represent things like touch and sensation in a minuscule amount of time. Mobile giant Ericsson is one of the companies working on this, and has called it the 'cyber-physical continuum'.

The same company also wants to create something called the 'internet of sensors', where things like physical touch or truly immersive experiences through next-generation augmented-reality glasses can be brought to life in vivid detail. Digital twin models will also be enabled by 6G. They allow experts to analyse what's happening in the physical world and simulate possible outcomes, anticipate needs and then take action back into the real world.

This all sounds really exciting, but we're not quite there with the technology yet. There are still few details on what 6G could actually look like in practice. The International Telecommunication Union (ITU) standardises wireless generations every decade, and it still remains to be seen how 6G will function. Most experts are predicting a launch date of around 2030 and for 6G to become fully commercially deployed by 2032, with companies like Huawei and Ericsson already laying the groundwork.

THE RACE TO 6G

With the future of communication within arms reach, companies and nation states alike are vying to be the first to make 6G a reality. The key players include the main network and wireless device providers such as Huawei, Samsung, Ericsson, Intel and Qualcomm. The Chinese and South Korean governments are also invested in taking the technology to the next level. Samsung is currently looking into the use of terahertz frequencies in order to build a network with an ultra-fast data transfer rate. Nokia and Ericsson are also developing networks which can operate in the 100 to 300 GHz frequency range.

China is currently making big strides in 6G technology research

Smart cities of the future will be connected by an invisible network of 6G signals

DID YOU KNOW? Touchscreen typing will gradually get replaced by gesture and voice control

EVOLUTION OF NETWORKS

The 6G network is just the latest in a series of networking advances

1G

This had very basic voice call capabilities, was launched by Nippon Telegraph and Telephone in 1979 and was at first only available in Tokyo.

2G

In 1991 the Global System for Mobile Communication launched in Finland, and a year later in the US. It featured encryption and a download speed of 0.2 megabytes per second.

3G

Launched in Japan in 2001, it had data speeds of two megabytes per second, enabling things like video chat and faster web browsing.

4G

Brought in at the end of 2009, this was a big improvement on 3G, with a download speed of 12.5 megabytes per second. But it required a new generation of mobile phones to make it work.

5G

The version most of us are familiar with today, South Korea introduced it in 2019 and it can be between 20 and 200 times faster than 4G. It opened up a new era of machine connectivity, which is still being fully explored.

6G

The latest technology could underpin things like remote surgery, immersive reality and real-time communication between machines and the human brain.

CHALLENGES AHEAD

As with any other great advance in technology, not everything is going to be straightforward, and there remains much uncertainty around the timescale for 6G, with some potential roadblocks to be cleared first. One issue is the lack of available spectrum. Spectrum essentially means the range of radio frequencies allocated to the mobile industry and other sectors for communication over the airwaves. The problem is that there's only so much of it to go around before it all becomes one big untidy mess where nothing makes sense, and 6G needs a lot more of this spectrum than 5G. Another issue is the sheer expense of creating 6G networks. They'll have to be designed and built from the ground up, covering land, air and space. Companies are still weighing up whether they'll be able to monetise 6G enough to recoup their costs and make a decent profit.

A 6G low-latency operated robot that mimics the movements of sensors

5G towers are now a common sight, but 6G will require its own infrastructure

HOW 6G WILL WORK

The new network will feature a range of technology working in concert

Did you know?
China launched the world's first experimental 6G satellite in 2020

SPACE NETWORK

22,236 MILES

1,242 MILES

186 MILES

AIRBORNE NETWORK

100 MILES

31 MILES

AIRSHIP FORMATION

6.2 MILES

DRONE FORMATION

CONTROL LINK

USER LINK

FEEDER LINK

100 METRES

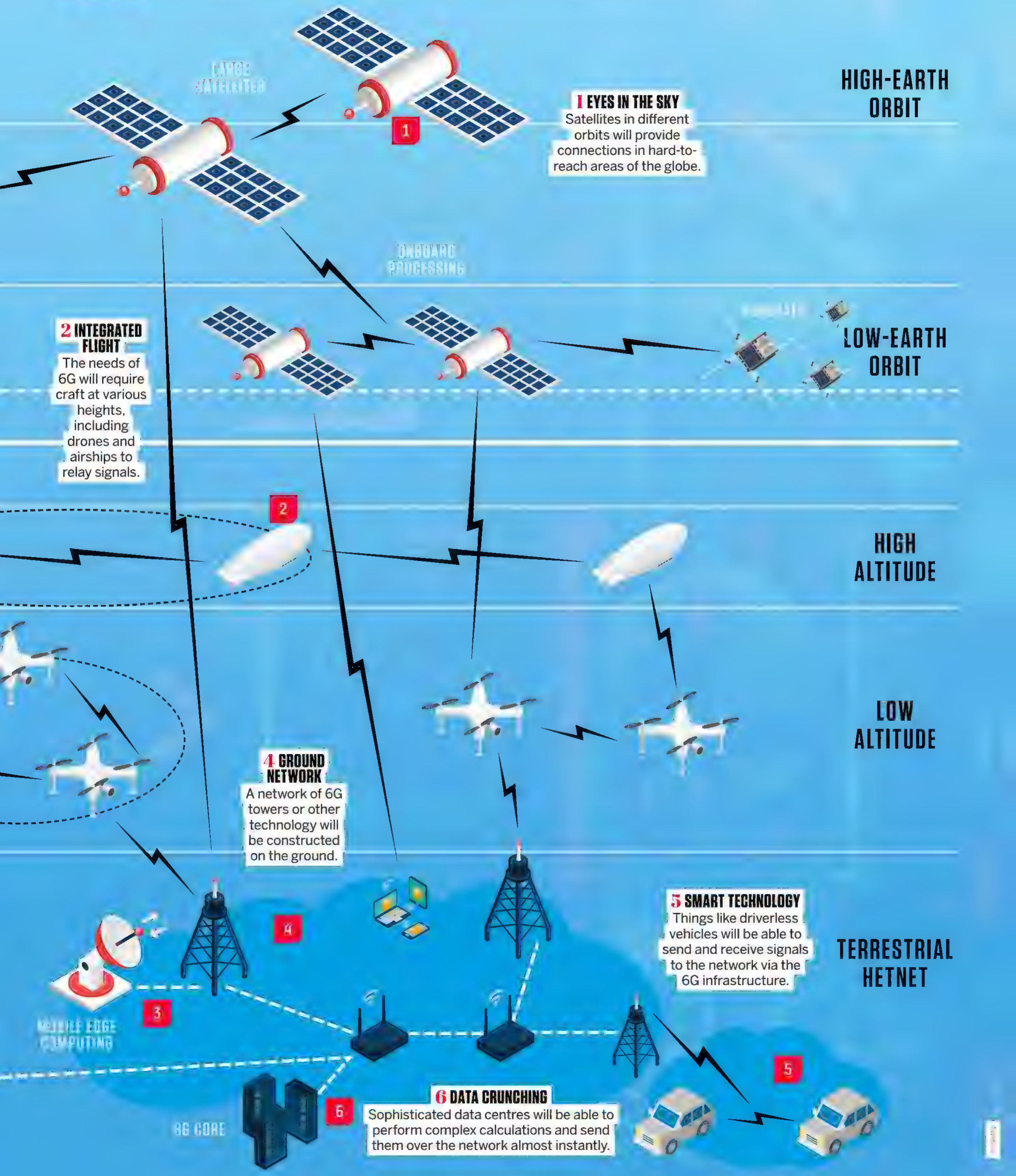
TERRESTRIAL NETWORK

3 MOBILE EDGE
Mobile edge technology will allow 6G signals to be processed faster at the source.

TELEMETRY, TRACKING AND CONTROL STATIONS

GATEWAY

DID YOU KNOW? Another benefit of terahertz-frequency signals is related to security and imaging



How virtual and augmented reality technologies are being used in a sophisticated military training tool

WARGA

DID YOU KNOW? Project OdySSEy was also developed by the company Aadean Supercomputing

GAMES

WORDS AILSA HARVEY

Can anything prepare you for war? In the armed forces, military personnel train to use weapons, are educated on the impact of crucial decision-making and learn how to command large dispersed groups on the ground. Usually, all of these techniques are learned in tightly controlled conditions on secure military bases until the skills are put to use in life-or-death scenarios. But logistically, large-scale live training sessions in the real world are very limited compared to the scope of an actual battlefield. This is where virtual reality can be of help. Project OdySSEy is a virtual military training platform developed by aerospace company BAE Systems, combining expertise in data analytics, virtual reality (VR), augmented reality (AR) and supercomputing. The collaborative project means that military training can take place remotely from anywhere in the world.

Trainees can connect to the VR software from various military bases and can work and communicate with their allies to complete realistic missions in virtual worlds. This involves a trainee wearing and manipulating a variety of apparatus depending on the level of physical activity required in each person's role, ranging from vehicle-simulating machines for soldiers on the battlefield to mixed-reality headsets for battlefield commanders and a simple laptop for those who work in intelligence and cyber security roles. Forces working on land, sea and air missions train together, connected to a single synthetic environment which they can plug in to at any time and location.

Work in the armed forces can be high risk, so it's essential that all members are trained thoroughly and know how to act in risky situations when on a real mission. As well as providing an accessible space for training activities, the virtual worlds generated in these immersive headsets are a sandbox to experiment in. Somebody who is flying an aircraft through hazardous skies has the space to make mistakes in a safe environment and learn from the catastrophic impact of small errors. When faced with the same situation on a real mission, the pilot will have benefited from this testing and is more likely to navigate obstacles safely and successfully.

SIMULATED STRATEGY

How battlefield commanders direct a virtual mission using Project OdySSEy

DID YOU KNOW? Live training is still essential for pilots to experience the physiological impact of jet flight

5 FACTS MODERN MILITARY TRAINING METHODS

1 SMART COMPUTERS
Computers can be trained with data to 'think' like a human in a battlefield simulation. They can predict what impact their decisions will have, helping soldiers learn their most effective course of action.

2 WATER ESCAPE
Water-egress training involves escaping from mock-ups of aircraft pushed into swimming pools.

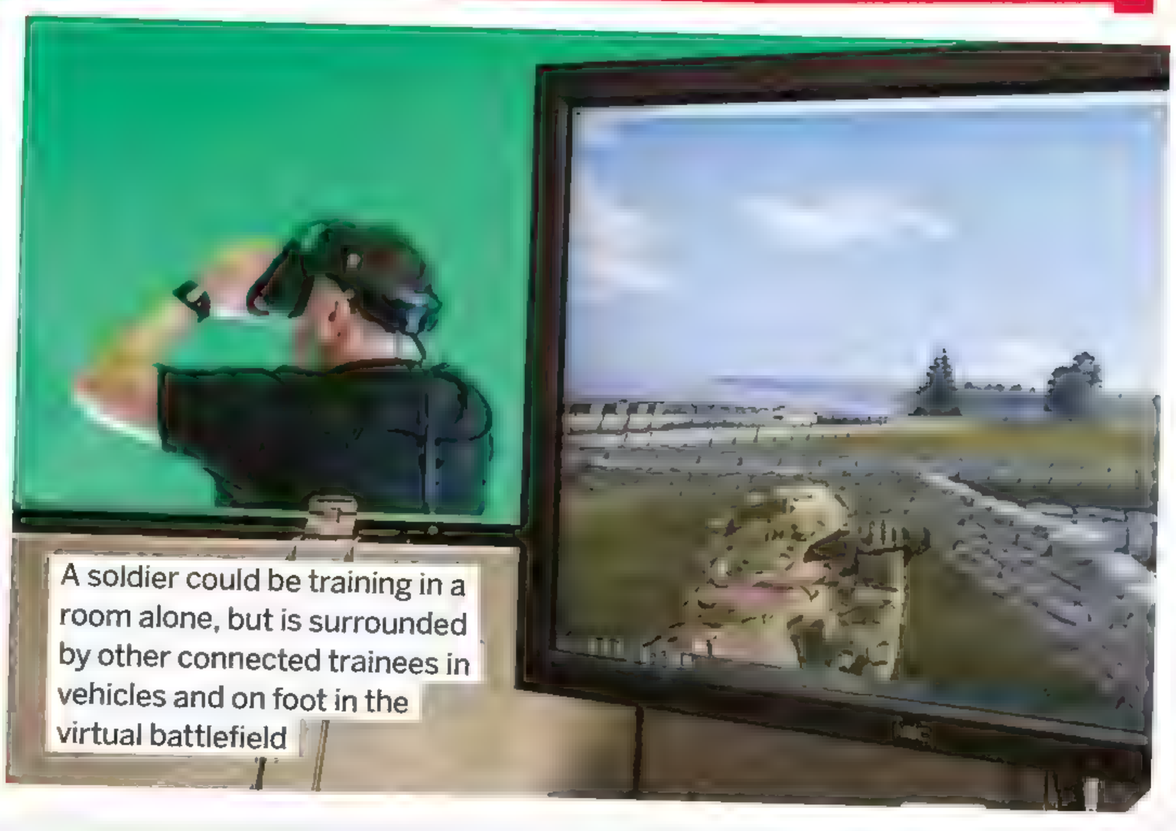
3 CYBER WARFARE
With security information stored as online data, armed forces provide simulated cyber-attack training. Participants need to strategise to defend their data.

4 NIGHT-VISION EQUIPMENT
Soldiers serve through day and night, so require training in night-vision technology. This includes goggles that enhance natural ambient light, thermal imaging cameras and infrared lasers.

5 HYPOXIC TRAINING
Altitude training sets soldiers up for work in high mountainous environments and aircraft. Masks that reduce their available oxygen enable this training to be conducted at any training base.

TRAINING BUDDIES

To increase military power and to assure mutual protection between countries, national armed forces ally themselves with others. These countries aren't necessarily close geographically, and that can make training as a single force problematic. The VR technology used in Project OdySSEy eliminates some of these issues by enabling invited personnel to join a training session from anywhere in the world. By connecting to a virtual-reality world, large groups of people can partake in regular joint training activities that would otherwise be difficult to organise. For countries like Australia, with multiple bases across a 2,485-mile-wide country, the technology can also be used to connect members of its own military. Travelling to engage in real-life training isn't replaced completely by simulation technology, but the evolution of this method means that militaries can unite as often as they wish to and with short notice.


A soldier could be training in a room alone, but is surrounded by other connected trainees in vehicles and on foot in the virtual battlefield

HOW THE VR HEADSET WORKS

The mixed-reality technology within Varjo's XR-3 headset seamlessly combines physical controls with virtual battle zones

1 LIDAR CAMERA
The light detection and ranging camera provides depth sensing by bouncing infrared light pulses off the physical simulator, the wearer's hands and arms to determine how far away from the headset they're positioned.

2 LIDAR
The infrared light is projected here. It has an operating range of 40 centimetres to five metres.

5 CAMERA MODULE
This module, which contains the cameras and sensors, is mounted to the ergonomic headband.

8 LIDAR MODULE WINDOW
The lidar's components are protected by optically coated glass. This is glass with anti-reflective properties to prevent interference with the laser.

6 BEZEL
The aluminium frame protects the cameras and sensors. It also gives cameras more space to achieve a wide field of view.

4 LIGHT TRACKING
Infrared LED lights project light onto your hands in sync with the camera's frame rate. Sensors use this to track your hand movements.

3 HAND-TRACKING CAMERA
This camera, developed by Ultraleap, tracks the movement of each finger at all times so you can interact with the virtual world using hand movements.

AN INTELLIGENT BATTLESPACE

When replacing physical training spaces with a synthetic world, artificial intelligence (AI) is essential in providing trainees with a realistic platform to make their own decisions and mistakes. Almost all of the decisions a trainee soldier will make during a mission will have an impact on a battle. The AI system is prepared with masses of training data, which includes a complex series of patterns and correlations.

AI can also produce realistic interactions with virtual surroundings, including intelligent agents. Intelligent agents are independent entities inhabiting a virtual world. For example, unlike the avatars of trainee soldiers, civilians in a virtual training battle zone aren't controlled by a real person. But with AI, soldiers can still interact with them and incorporate this aspect of a mission into their training. This is something soldiers would usually not encounter until they were on a real-world mission. Machine-learning algorithms mean that every time a military virtual training exercise is completed, the computerised characters learn from human interactions and begin to react with increasing realism.


AI can alter how the virtual world reacts based on the location and landscape

DID YOU KNOW? The Varjo headset tracks your eyes at 200 movements per second

One of the flight-simulation machines that can be plugged into Project OdySSEy

7 VIDEO PASS-THROUGH CAMERA
Captured video from dual 12-megapixel cameras passes through the headset, where real-life items are merged convincingly with VR. This prevents VR appearing like a hologram in the viewed footage.

Did you know?
The first VR headset was invented in 1968

Personnel who may be many miles apart can work together in one room in a virtual battle zone

VIRTUAL VERSUS REALITY: THE TRAINING IN ACTION

Project OdySSEy's head of training Lucy Walton describes her experience with launching VR missions

What are the main benefits of the armed forces using this VR training tool?
Sustainability is definitely one. Not doing training live saves a huge amount of emissions, and it's repeatable. When you're doing something live with an aircraft, you're going to get one shot because you're going to run out of fuel and need to go back. With VR you can restart a scenario at the push of a button. I speak to a lot of the aircrew who say this would be beneficial for them – knowing they can rehearse and do wrong now so that they learn all those key points before doing it live in the air.

Does it improve tactics?
There's almost no part of the Earth that isn't monitored anymore, with people watching 24 hours a day, seven days a week. In the simulated environment, we can deploy more realistic tactics than you would live. We have to redact them when we do it live because we don't want people to be able to see what we're up to.

How true to life are the simulated training locations?
Essentially, you can take any part of the world from a terrain perspective, and there's lots of companies we're working with at the moment that are starting to develop streaming services, so you can almost stream that terrain and the updates live. We take images from satellites and very quickly put that through an AI engine. It will recreate what that looks like from a simulation terrain. As you're starting to move towards more realistic live exercise rehearsals, you need that terrain to be updated much more frequently, because one day a building might be there and the next day it might not.

How predictable are the AI environment and civilian reactions in the simulations?
AI changes how civilians behave each time. For example, we had some simulated people that we wanted to leave a scenario, so we brought in some really low-level aircraft, which is called a show of force, and those people ran away very scared. Then we did it again, and a third time. By the third time they stopped running, as they had learned nothing bad happened afterwards, so they started to walk away, rather than running away terrified. It's quite interesting to see how their behaviour set learned that.

Historically, when we've done training in this way, everything is controlled by humans. The exercise director knows everything that's going to happen in an exercise before it starts. When you start to inject AI, it changes. In one exercise, we had a convoy of cars that were going to do a resupply mission, and a civilian crashed on the road. We're working to balance keeping the AI realistic and training people when you don't necessarily know the scenario.

HOW FLAMETHROWERS WORK

These tools that hurl plumes of fire through the air were originally weapons of war

WORDS SCOTT DUTFIELD

Different forms of flamethrowers have existed for thousands of years, but the first handheld flamethrowers emerged during World War I. A creation of the German army, early handheld flamethrowers consisted of backpack-style fuel tanks with gun-like nozzles that, when ignited, released a torrent of flame towards their enemies. Used again in World War II and the Vietnam War as incendiary weapons, it wasn't until 1980 that their use was restricted under Protocol III of the Geneva Convention. Today the main role of flamethrowers lies in land management, such as eradicating invasive plant species, clearing croplands and burning land to recycle nutrients.

For a flamethrower to work, it needs to supply two of the three basic ingredients that cause the reaction that leads to fire: heat and a fuel source. The third ingredient, oxygen, comes straight from the atmosphere. To supply the heat, flamethrowers supply an initial spark when the trigger is pulled and the fuel released. Once the spark ignites the fuel, the heat generated by the fire becomes enough to sustain the reaction. As long as the trigger is held down, gasoline or diesel continues to feed the reaction with atmospheric oxygen.

With all the ingredients needed to create fire, flamethrowers need a way to prevent the flames from travelling back up the device into the tank – with explosive results – when the trigger is pulled. This is achieved by adding a tank of pressurised gas. When the trigger is pulled, the gas forces the fuel through the nozzle, creating a continuous stream of fire in one direction. When the trigger is released, a valve cuts the fuel and oxygen supply off, preventing fire from forming within the flamethrower. This pressurisation also means that flamethrowers can shoot fire over impressive distances. For example, flamethrowers used in World War I could spray fire over 40 metres.

Some countries, such as China, maintain the use of flamethrowers in their armies

A illustration of Greek fire from a Byzantine manuscript

Did you know?

Orange flames burn up to 1,200 degrees Celsius

GREEK FIRE

Flamethrowers aren't a modern invention. In the Byzantine Empire of the late 7th century, a new form of warfare was introduced by an ancient architect named Callinicus of Heliopolis. The incendiary weapon, known as Greek fire, consisted of a liquid fuel that was heated and then pressurised before being ignited and sprayed through a syphon, typically onto the hulls of invading ships. The exact concoction of chemicals used to create the blaze is unknown, but it's been suggested that petroleum and sulphur may have been key ingredients.

As a weapon, Greek fire was a formidable foe, as water could not stop the liquid fire from burning. At the time, one of the only known ways to extinguish the fire was by covering it with sand or vinegar.

DID YOU KNOW? In 2018, Elon Musk's Boring Company sold over 20,000 flamethrowers

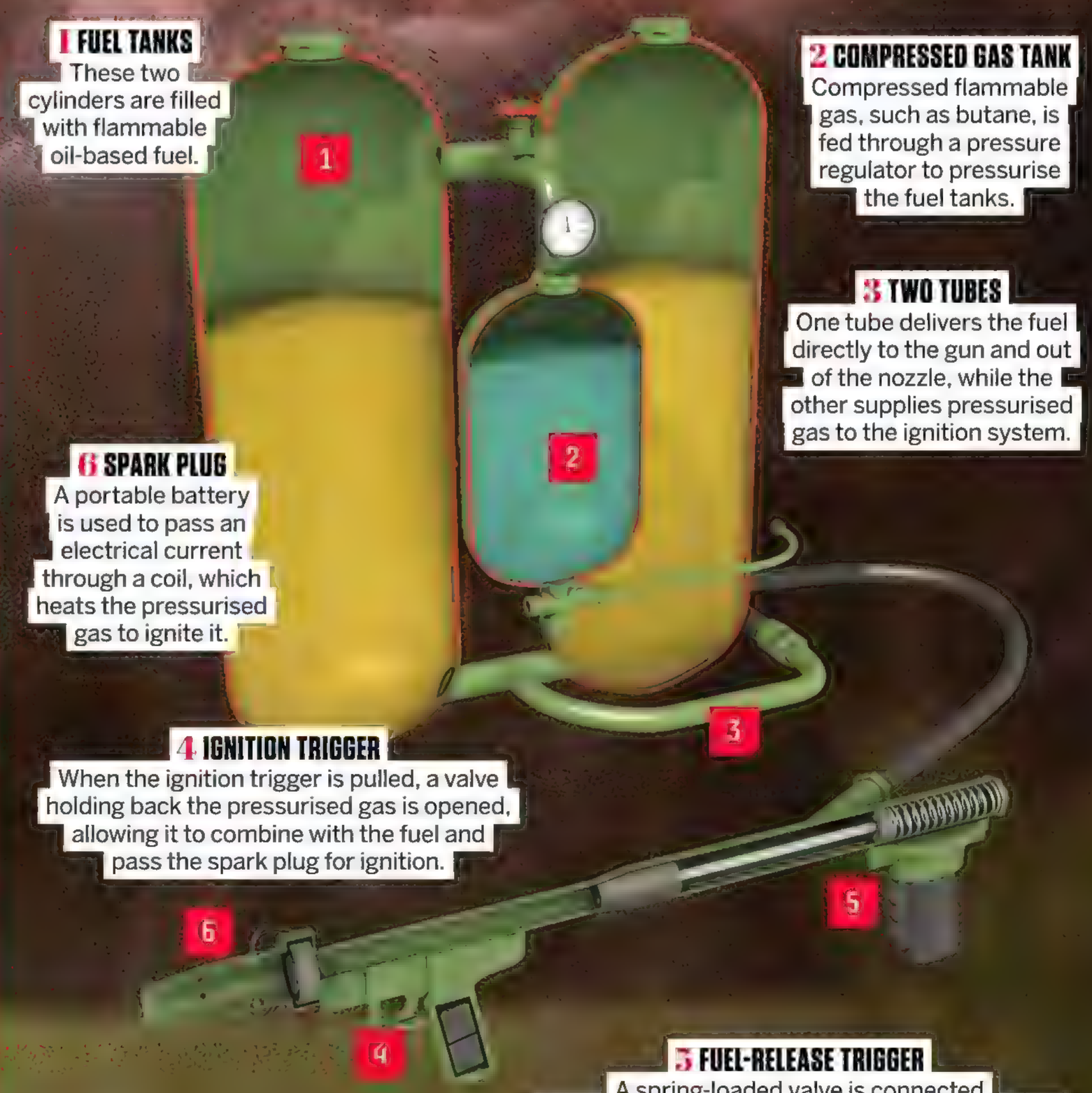
FIGHTING FIRE WITH FIRE

One of the last things you'd expect to see near wildfire is a firefighter holding a flamethrower. Nevertheless, they can be one of the best tools for stopping fire from spreading. Every year, tens of thousands of wildfires sweep through forests and grasslands around the world, destroying habitats and homes. To stop the spread, firefighters use flamethrowers to create what's known as a 'backfire'. This deliberate and controlled fire consumes some of the vegetation in a belt ahead of a spreading wildfire. By the time the wildfire reaches the belt of burnt ground or forest, there is no more fuel to feed the fire, and so the wildlife can't progress any further.

A wildfire raging through a forest in Colorado, destroying wildlife

INSIDE A FLAMETHROWER

These ingredients and components allow the user to spout fire with the pull of a trigger



1 FUEL TANKS
These two cylinders are filled with flammable oil-based fuel.

2 COMPRESSED GAS TANK
Compressed flammable gas, such as butane, is fed through a pressure regulator to pressurise the fuel tanks.

3 TWO TUBES
One tube delivers the fuel directly to the gun and out of the nozzle, while the other supplies pressurised gas to the ignition system.

6 SPARK PLUG
A portable battery is used to pass an electrical current through a coil, which heats the pressurised gas to ignite it.

4 IGNITION TRIGGER
When the ignition trigger is pulled, a valve holding back the pressurised gas is opened, allowing it to combine with the fuel and pass the spark plug for ignition.

5 FUEL-RELEASE TRIGGER
A spring-loaded valve is connected by a rod to the trigger. When the trigger is pulled, the valve opens and the fuel is released.

TECHNOLOGY

ESSENTIAL GADGETS OF THE 1980s

How the must-have radical gadgets that dominated the 'decade of decadence' worked

WORDS SCOTT DUTFIELD

CLAP ON, CLAP OFF

Long before Alexa could take control of your home gadgets, the 1980s welcomed the Clapper, a compact device that could remotely switch on appliances. With the catchphrase "clap on, clap off, it's the Clapper", the function of this device isn't difficult to grasp. Simply plug in a lamp, radio or TV to the Clapper and the sound of a clap would either turn it on or off. The device worked using a small microphone connected to a sound filter. When the microphone picked up a clapping sound, typically between 2,220 and 2,800 hertz, the sound filter triggered an electrical signal to the power switch, turning the connected appliance on. Two claps in succession triggered an electrical signal that turned the power outlet off.

Along with improving home convenience, the Clapper also came with a security 'away' feature. When switched to away mode, the sensitivity of the microphone was increased, making the slightest noise detectable. The idea was that when an intruder moved through the house, the noise would be detected, turning lamps and the TV on and startling the intruder – hopefully sending them packing. Originally released in 1984, the Clapper could be found in homes throughout the decade and beyond. Even today, clapper technology is used to switch lamps around the world on and off, including novelty *Star Wars* Darth Vader and Yoda devices that require you to use the clapping 'force'.

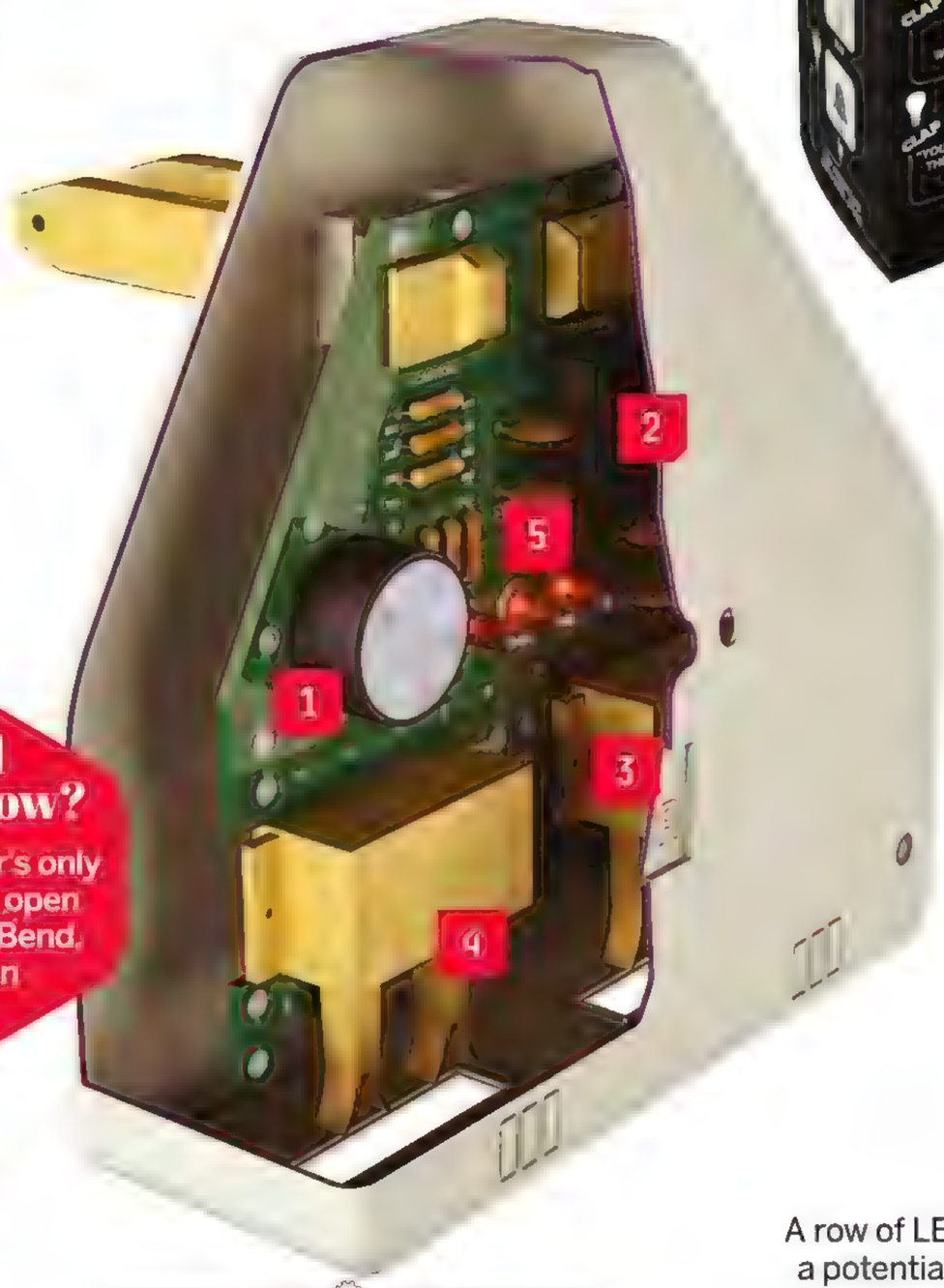
Did you know?

Blockbuster's only remaining open store is in Bend, Oregon

You can still purchase the Clapper in many novelty forms, such as this Darth Vader head

INSIDE THE CLAPPER

The parts that put the sound of clapping hands to good use



1 MICROPHONE
Sound is picked up by the microphone and a filter determines if a clap has been detected.

2 IT'S A CLAP
When a pattern of claps is detected, a signal is sent to the power controller.

3 POWER CONTROLLER
With the correct clap sequence, the power controller will direct power from the mains to one of two power outlets.

4 POWER OUTLET
There are two power outlets at the base of the Clapper. A predetermined sequence of claps is assigned to each outlet to switch it on or off.

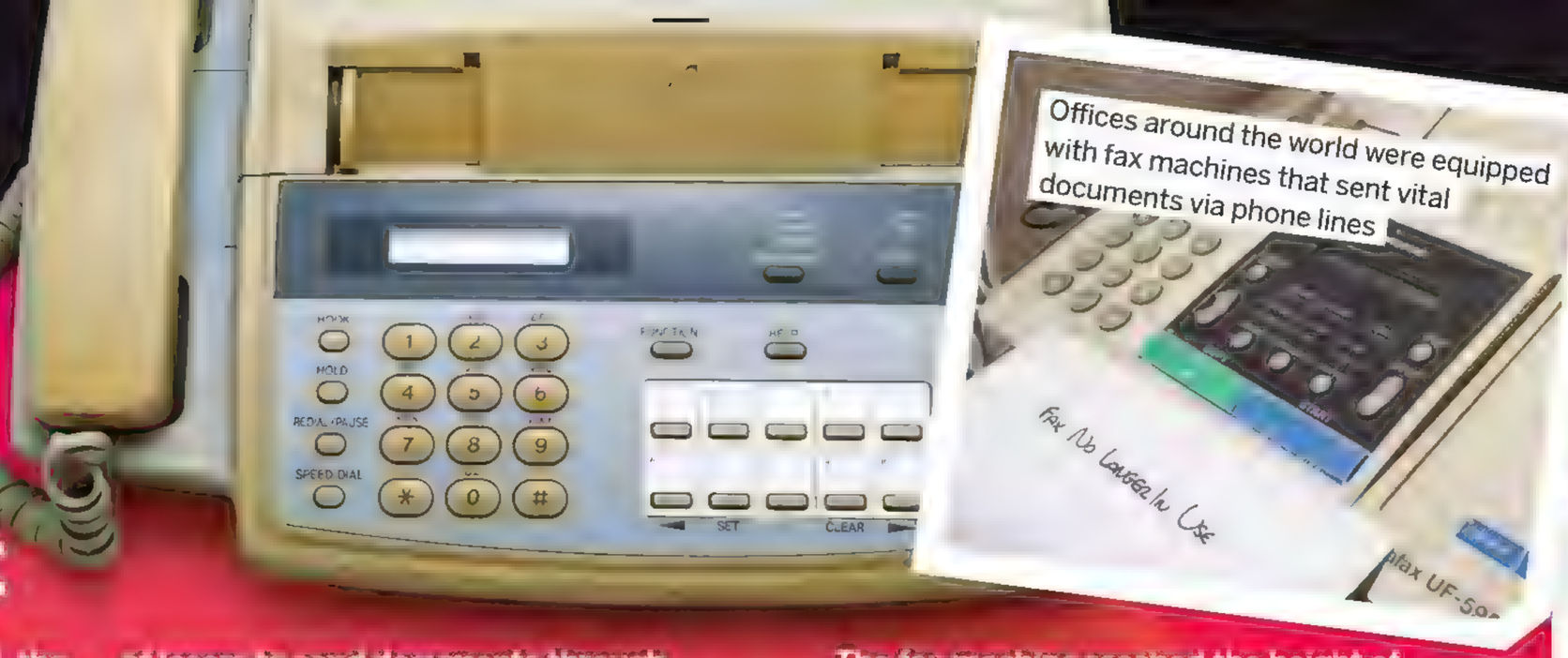
5 LEDS
A row of LED lights indicates when a potential clap is heard. If only a couple of lights flash, the clap is not loud enough to register.

PERSONAL PAGER

Originally invented in the 1950s, the pager evolved into one of the 1980s' must-have gadgets, with more than 3 million users worldwide. As a form of one-way communication, they enabled the sender to send digital messages, typically telephone numbers or extensions, as a prompt for the receiver to get in touch. Through a network of radio transmitter antennae, messages were sent via radio waves, connecting people using a personal code number, much like today's mobile numbers. When a message was received, the pager lit up and beeped, and the message would be displayed on the pager's LCD display. They found particular popularity among hospital workers due to their fast and efficient messaging system, as well as the ability to operate on a local radio network, meaning that communication could be isolated to a single hospital.

Pagers typically came with a convenient clip that allowed them to be held on a belt or waistband

SENDING DOCUMENTS OVER THE PHONE



As the precursor to modern-day email, the humble fax machine was a staple in any office of the 1980s, used to send and receive documents. At one end of the transmission, a person simply inserted the pages they wanted to send into the device, which were scanned internally and sent through the phone line to the receiver as binary data. The receiving fax machine decoded this binary information and began to print out identical copies of the pages.

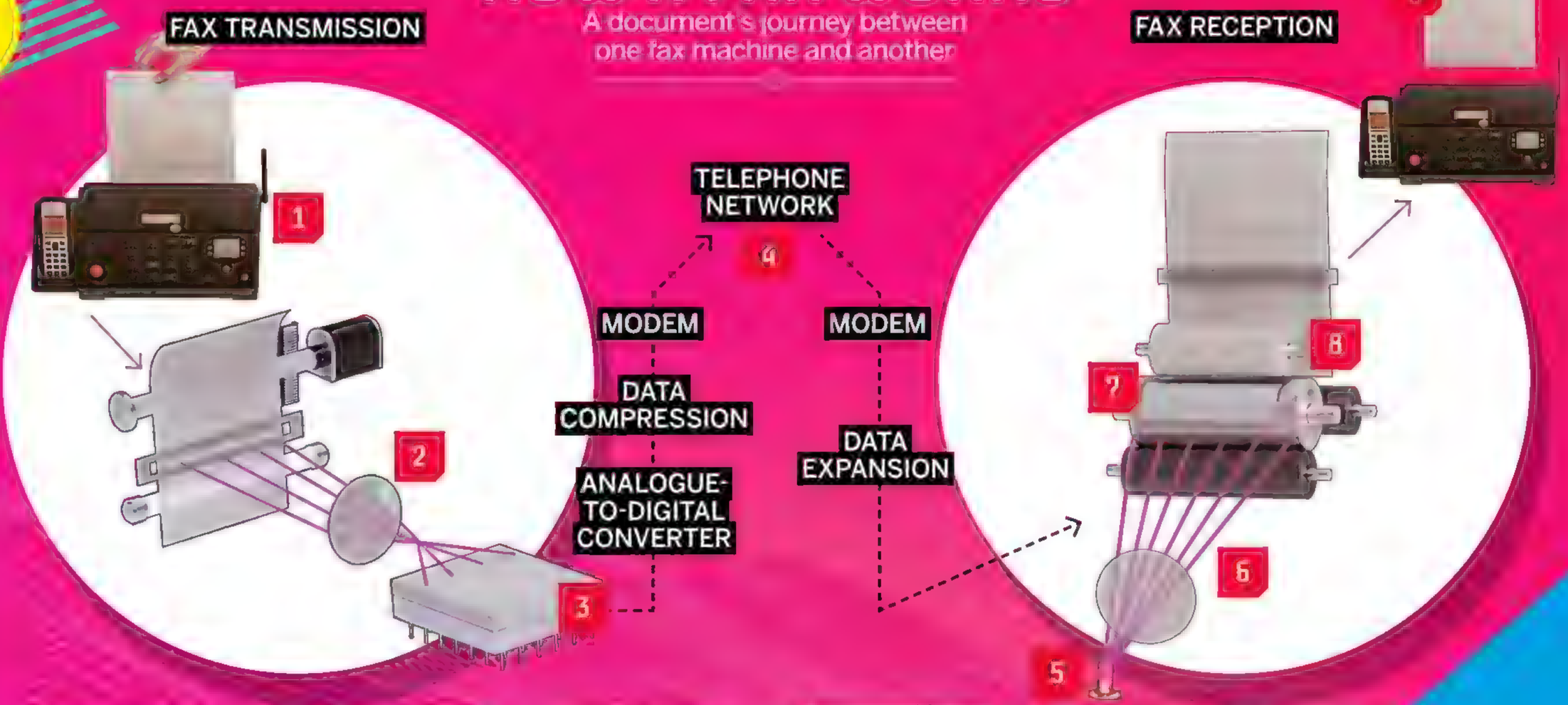
The printing technologies used by fax machines evolved over the decade, from heating thermal-sensitive paper to the use of lasers to send documents through a process called xerography – a method of creating an image that was originally invented in the 1930s. The process used light and electrically charged ink to interpret the black and white spaces on a document, which were recreated to make accurate copies.

It wasn't until 1985 that the first computer-based fax machine, called the GammaFax, was released by American computer hardware company GammaLink, which was the precursor to the internet-based fax machines of the 1990s.

The fax machine reached the height of its popularity throughout the 1990s and into the early 2000s, when email became the preferred form of communication for many businesses. In 2003, the UK's communications regulator Ofcom set up the Universal Service Obligation (USO), promising to maintain network support for fax communication to support people who weren't connected to the internet. The USO continued fax support for 20 years, but in 2023 Ofcom announced the service would end, bidding a final farewell to the fax machine.

HOW A FAX WORKS

A document's journey between one fax machine and another



1 FEED THE FAX
A document is fed into the machine, where it's caught by a feed roller that moves it through.

2 CCD
A fluorescent bulb shines light through the document and is detected by the charge-coupled device (CCD) sensor.

3 ELECTRICAL SIGNAL
The CCD generates electrical impulses through the phone when it detects the shape and structure of the black text on the document.

4 ELECTRODES
A series of electrodes send an electrical signal through the phone line to the receiving fax machine.

5 RECOVERING INFORMATION
The electrical signal received by a fax machine is processed and recreated through a laser light source.

6 LASER
A laser beam is passed through a mirror and lens to hit a photoreceptor ink drum at points that correlate with the blank space around the letters and words on the original document.

7 PHOTOSENSITIVE DRUM
Where the negatively charged photosensitive ink is touched by the laser, it becomes positively charged and remains on the drum.

8 PASSING PAPER
The remaining negatively charged ink is free to adhere to the paper to replicate the text of the original document.

9 PRINT OUT
Once the whole page has been printed, a fresh copy is released from the fax machine.

DID YOU KNOW? By 1987, 20 [illegible] was in the US

If you needed to do a quick sum on the go, the Casio Calculator watch had you covered

WRISTWATCH CALCULATOR

Bringing calculator convenience to your wrist, the Casio Calculator watch was worn by many during the 1980s, including Marty McFly as he travelled through time in *Back to the Future*. Unlike ordinary digital watches, these innovative timepieces came equipped with a ten-digit keypad to carry out basic calculations, which were displayed on its liquid crystal display (LCD) screen. The first of Casio's calculator watches was the C-80, released in 1980, followed by the upgraded Databank Telememo CD-40 in 1984. The CD-40 could store up to 30 records – including names and telephone numbers – do trigonometry and included TV remote control functions. By the mid to late-1990s, Casio's wrist-worn calculators had faded in popularity.

'THE BRICK' MOBILE PHONE

In 1983, the first 'mobile phone' was released in America by Motorola. Called the DynaTAC 8000X, it was also known as 'the brick' because it weighed over a kilogram. The portable phone batteries were capable of just 30 minutes of phone time and took around ten hours to charge. Though it was the first commercially available mobile phone, it came with a hefty price tag of $3,995 – equivalent to around £9,700 in 2024.

The DynaTAC operated on the first-generation analogue mobile network and used the newly developed advanced mobile phone system, released in the US, to make calls. The advanced mobile phone system used analogue frequency modulation to transmit speech throughout geographic regions known as cells, hence the name 'cell phone'. These cells had a radio base station at the centre with a designated reception area covering several square miles, transmitting mobile frequencies to other base stations until they reached the target mobile phone.

At the time of its release, DynaTAC had access to pre-existing base stations in the US. However, the innovative phone wouldn't reach the UK due to its lack of base station infrastructure. The first UK base stations were introduced in 1985, which came in time for the next instalment of the 'brick' phone, the Motorola 8500X, which quickly swept across Europe.

Did you know?
MTV went on air in 1981

Inventor Martin Cooper holding a DynaTAC 8000X in 2023 at the Mobile World Congress in Barcelona

NES GAMING

First released in Japan in 1983, the Nintendo Entertainment System (NES) was one of the biggest gaming consoles of the decade, selling more than 62 million units. The NES brought some of the most iconic games to life, such as *Super Mario Bros.* and *The Legend of Zelda*. The NES was one of the first 8-bit gaming consoles, providing a quality of games unlike anything else at the time. Today's gaming consoles have much more powerful processing units, such as the PlayStation 5, which has a 64-bit processor inside. Along with its pioneering gameplay, the NES came with equally revolutionary accessories, such as the Zapper, a light gun for pistol-shooting games like *Duck Hunt*, and the Robotic Operating Buddy, or R.O.B, which acted as a second player for games such as *Stack-Up*.

The NES came with two wired controllers and weighed less than 2.5 kilograms

Did you know?
The last casette Walkman was made in 2010

SOUND OF THE 1980S

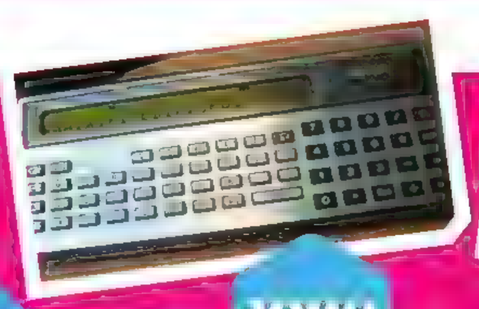
Throughout the 1980s, you'd be hard-pressed to pass someone without one of the most iconic gadgets of the decade clipped to their belt: the Sony Walkman. Released in 1979, this portable cassette player was the best way to listen to music on the go. The Walkman relied on the same magnetic tape technology as the VHS, albeit on a much smaller scale.

Sound waves were recorded and converted into a unique electrical impulse to create a magnetic imprint of a song onto the tape. A cassette filled with spooled tape was then loaded into the Walkman and the play button was hit. The magnetic tape was passed by an auditory reader head to interpret the information and convert it into electrical impulses, which were translated into sound. That sound was then heard through a pair of wired headphones plugged into the Walkman. Hitting rewind rewound the tape from one spool to another and fast forward simply wound it in the opposite direction, moving quickly backwards or forwards through the recorded audio.

Much like VHS, the Walkman eventually fell prey to the innovation of the compact disc (CD). Sony jumped to create one of the first portable CD players, called the D-50, just a year after the CD was introduced in 1982.

A Sony Walkman on display in the Toshiba Gallery of Japanese Art in 2015

GREATEST GADGETS



1980

THE SHARP POCKET COMPUTER
A portable calculator and computer with a full QWERTY keyboard.

1982

SPEAK & SPELL
This children's learning toy was propelled into the limelight by a cameo in *E.T.*.

1982

ZX SPECTRUM
This home computer with full-colour graphics was released in the UK by Sinclair Research.

1983

CAMCORDERS
In the early 1980s, many different handheld video-recording devices emerged, such as RCA's VHS camcorder.

1984

ANSWERING MACHINE
Affordable answering machines became popular following the breakup of the Bell System.

DID YOU KNOW? The Sony Walkman was originally released as the 'Soundabout' in the US and 'Stowaway' in the UK

RISE OF THE VIDEOTAPE

The Video Home System (VHS) burst onto the scene during the 1970s but hit its stride by the mid-1980s. VHS cassette tapes relied on an invention from the 1920s called magnetic tape. Using a thin plastic base, the magnetic core of the tape was largely made up of a layer of metal oxide, typically iron oxide. When particles of iron oxide were exposed to a magnetic field, their orientation permanently changed until they were exposed to another magnetic field – a quality that's known as ferromagnetic. When recording onto magnetic tape, the image and audio were converted into electrical signals that passed through an electromagnetic field in a device called a recording head. As the tape passed the recording head, the particles of iron oxide oriented themselves in unique ways to form a magnetic imprint of a film.

When a VHS cassette was placed inside the VHS player, the magnetic tape moved from the supply reel to the take-up reel while passing a rapidly spinning drum, which was equipped with similar magnetic heads to 'read' the information on the tape. This was known as helical scanning. The heads then generated an electrical signal for the television to interpret, displaying images and sound on screen.

READING TAPE

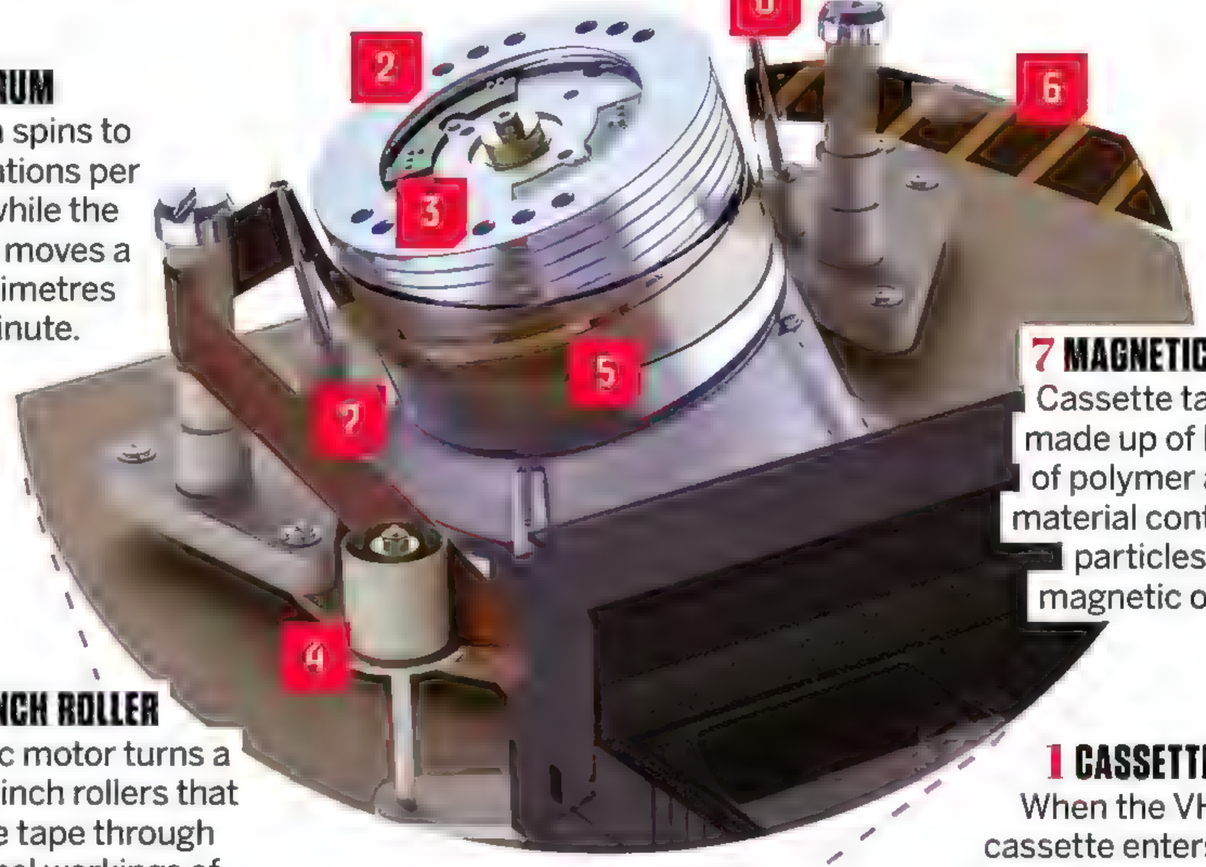
How VHS players translated magnetic tape into movie magic

6 RECORDING TRACKS
The visual and audio recordings are stored in diagonal lines on the magnetic tape to maximise the amount of information on the tape.

2 TILTED
The drum is tilted to line up the recorder heads with the diagonal recorded tracks on the magnetic tape.

5 HEADS
The information on the magnetic tape is 'read' by fast-spinning recording heads in the centre of the drum. VHS players have either two, four or six heads on a drum.

8 GUIDE POSTS
These tractable posts move the magnetic tape in and out of the VHS cassette.



3 DRUM
The drum spins to 1,800 rotations per minute while the tape only moves a few centimetres per minute.

7 MAGNETIC TAPE
Cassette tape is made up of layers of polymer and a material containing particles of magnetic oxide.

4 PINCH ROLLER
An electric motor turns a series of pinch rollers that move the tape through the internal workings of the VHS player.

1 CASSETTE
When the VHS cassette enters the player, a flap at the top is lifted up and the tape can be pulled towards the drum.

VHS tapes play at a speed of 24 frames per second

1984

FIRST MACINTOSH
Apple released the first Macintosh computer, which packed just 128KB of RAM.

1985

TEDDY RUXPIN
This talking teddy bear could move its eyes and mouth, telling stories that were played on a cassette tape in its body.

1985

SINCLAIR C5
Sinclair Vehicles released this battery-operated tricycle, which could reach 15 miles per hour.

1987

KODAK FLING 200
Kodak brought affordable disposable cameras to the masses.

1989

GAMEBOY
Nintendo launched this 8-bit handheld gaming console and future icon of gaming.

APPLE VISION PRO TEARDOWN

This new mixed-reality headset removes the need for a screen, bringing your digital applications into the space around you

WORDS AILSA HARVEY

Screen time can often mean being stuck in one place, inactive and much less aware of your surroundings. Virtual reality (VR) headsets solve this problem by blocking out the real world and placing you completely in a new one. The Apple Vision Pro has similar features to other VR headsets, but incorporates digital simulations of the real world with other elements overlaid. Wearers can see and communicate with other people while using it, and other people can see a 3D image of the wearer's eyes through the glass and via 3D cameras.

The Apple Vision Pro can connect to all Apple applications you have on other Apple devices, while other Apple devices can connect to it instantly. By simply looking at the screen of your linked MacBook, you can virtually enlarge it in your eyeline, move it around and use your fingers to make it as big as you want. The same can be done when watching a film on a streaming application. By dragging the screen's corner, you can transform it into a cinema screen-sized simulation. You can also change the background by turning a dial on the headset. This alters how immersed you are in the real or virtual environment of your choice. Instead of watching your shows from the sofa, you can watch them in the virtual outdoors or even on a different planet.

Aside from entertainment, the mixed-reality headset can be used to create content using Apple's first 3D camera. The wearer can record videos of their surroundings from their point of view and watch them back in 3D. When video calling a friend, this technology allows a person's 3D image to be relayed at life size in the room of the headset wearer. The idea of this feature is to make long-distance calls more connected by creating the illusion that the other person is in the room with you. As the headset covers the person's face, the other caller will see a simulated version of the Apple Vision Pro user's face on their Apple device. The cameras in the device capture all of the facial expressions you make and combine footage to display a real-time image of you speaking without a headset on.

6 BRIGHTNESS OPTIMISATION
This screen has a brightness-enhancing film inside for clearer views of the wearer's eyes.

3 ADJUSTABLE HEADBAND
This stretchy, 3D-knitted strap wraps around the back of your head and can be size adjusted by turning the circular dial.

Did you know?
The headset and battery weigh over one kilogram

9 CAMERA ARRAY
5 sensors, 6 microphones and 12 cameras record and incorporate your surroundings into the display.

10 COMPUTER CHIPS
The headset is powered by dual chips. The M2 chip controls graphics and the R1 chip transmits video and audio within 12 milliseconds.

DID YOU KNOW? Panoramic photographs wrap around the wearer, fully immersing them

INSIDE THE HEADSET

How does this device combine the real and digital world?

2 BATTERY PACK
The 35.9-watt-hour battery pack is worn in the user's pocket. When fully charged and disconnected from power, its batteries last for 2.5 hours of video watching.

5 LIGHT SEAL
This metal and fabric component comes in 28 different sizes to fit a variety of face shapes. The material blocks out any surrounding light, and magnets attach it to the eyepiece.


When not in a fully immersive setting, other people can see the wearer's eyes

4 FACE CUSHION
Polyurethane foam lies between the headset and face to provide soft cushioning.

1 GLASS PANEL
The Apple Vision Pro has a glass front so that users don't need to remove the VR headset to see people and items in the room.

7 EYE LENS
The concave lenses give each eye a wider field of view.

8 SINGLE EYE DISPLAY
There is one small display for each eye, with resolution just under 4K.

The white oval components at the sides of the device are speakers that direct sound backwards into your ear

EYE, HAND AND VOICE CONTROL

Without a keypad, screen or physical controls to interact with, how do you operate the Apple Vision Pro? Everything can be controlled by moving your eyes, arms and hands. Eye-tracking systems incorporated into the camera array include LEDs and infrared cameras. These scan the eyes with invisible light to track their movements. When on a screen with multiple options, each one will light up or move when you focus your eyes on them. When you have chosen an application, you need to tap your index finger and thumb together in front of you to select one. To type words you can touch the virtual keyboard with your fingers in the air, or use the speech-to-text function. Voice controls can be used to bring up other applications across the device. When moving a screen, pinching with your finger and thumb zooms the screen in and out, pinching and dragging moves screens and swiping enables quick scrolling.


The Apple Vision Pro responds to numerous motions


TRANSPORT

ALL ABOUT SCOOTERS

AILSA HARVEY

Discover the history and technology behind these urban commuting vehicles

DID YOU KNOW? In the UK, non-commercial electric kick scooters can only be ridden on private land

DAWN OF THE AUTOPED

The first motorised scooter was called the Autoped. It looked very similar to today's electric kick scooters, but ran on gas with an engine attached to the front wheel. The Autoped was first sold in the US in 1915 and could cruise American streets at speeds of around 20 miles per hour. This invention was the first demonstration of a craze that would gain widespread popularity almost a century later.

But when Autopeds first appeared on New York's streets there was a lack of safety regulations, and traffic lights were 15 years away from being installed.

The early scooter was designed for almost anyone commuting around cities, but it soon became known as a symbol of women's independence. Suffragettes such as Lady Norman used this modern transportation method for solo travel to their workplaces. Many businesses, such as the New York Postal Service, also used the scooters to increase work efficiency in cities.

Suffragette Lady Norman pictured on her scooter, which she used to travel to her office in London

E-SCOOTER MECHANICS

These electric vehicles are increasingly popular for short-distance travel in urban locations

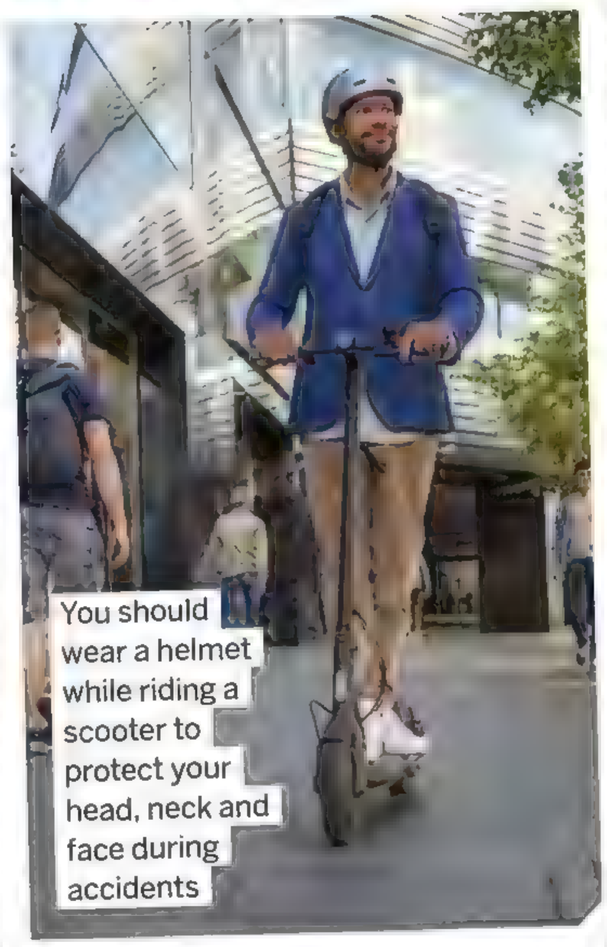
7 ACCELERATION
To start the e-scooter, a rider must push it along the floor manually before placing both feet on the platform and holding down the accelerator button.

1 INFORMATION DISPLAY
This LCD display can be used to show street maps and navigation, as well as important statistics like battery level and speed.

3 TRANSMISSION
This system connects the motor and wheels. It transfers the motor's power directly to the wheels without requiring complex gear shifting.

6 BRAKE LEVER
When squeezing this lever, brake pads slow down the rotation of the wheel using hydraulic force. If the lever is pulled back fully, the e-scooter is brought to a stop.

2 MOTOR
The motor converts the battery's electrical energy into kinetic energy to move the scooter's wheels.



You should wear a helmet while riding a scooter to protect your head, neck and face during accidents

5 HEADLIGHTS
For travelling in the dark or low light, scooters have headlights for the rider's visibility and to alert other road users of their presence.

9 KICKSTAND
This small metal protrusion lies horizontal to the scooter during riding. When parked, it's kicked to rotate it downwards. The kickstand serves as a stand to park the scooter upright and stop it falling over.

8 INDICATORS
E-scooters travel at 30 miles per hour. Indicators are essential to alert other commuters of the rider's intended movements.

4 POWER SOURCE
The standing platform, or deck, has a lithium-ion battery inside. Usually, these scooters can ride around 12.4 miles between charges.

INSIDE AN ECO-FRIENDLY MAXI SCOOTER

This hydrogen-powered Suzuki Burgman prototype uses clean fuel

1 FUEL REFILL
Hydrogen is injected from a hydrogen refuelling station into the scooter through a nozzle inserted here. It takes around double the time taken to refuel a petrol scooter.

2 FUEL CELL
Electricity is generated here when pure hydrogen gas is split into protons and electrons. Electrons flow in an electric current before recombining with the protons and oxygen from the air to be released from the vehicle as water.

3 HYDROGEN CONTAINER
Compressed hydrogen gas is stored in this 12-litre container. This is the most abundant element in the universe.

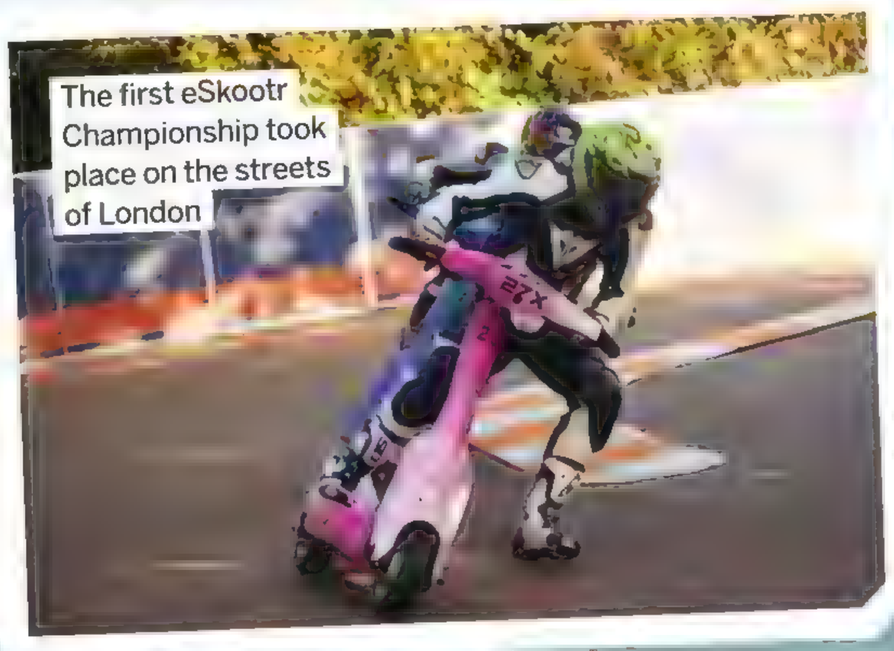
4 LITHIUM-ION BATTERY
Electrical energy from this battery is used during acceleration. When the vehicle is cruising, the fuel cell recharges the battery.

5 ELECTRIC MOTOR
The motor receives electrical energy and converts it into kinetic energy to turn the scooter's wheels.

6 COIL SPRING SUSPENSION
Steel springs are mounted onto shock absorbers. This means the wheels can move separately from the vehicle's chassis, while the springs expand and compress to absorb the impact of driving over rough terrain.

CHAMPIONSHIP COMPETITION

Despite being designed for controlled commutes, faster versions of electric kick scooters are manufactured for race tracks, achieving speeds over 60 miles per hour. The eSkootr Championship is the first global competition based on the scooting craze. The racing scooters have a thicker carbon-fibre chassis and weigh just 35 kilograms. The wheels on these light vehicles have enough grip to enable riders to lean at angles up to 55 degrees on tight corners, and with all competitors meeting the same scooter specifications, the result is a close-proximity scooter dash. 30 riders compete at one time in the racing series, which was launched in 2022. One of the goals of this competition is to promote electric scooters as environmentally friendly urban transport alternatives.


The first eSkootr Championship took place on the streets of London

DID YOU KNOW? In Germany, 15 per cent of the population aged 16 and over use e-scooters

5 FACTS ALL-TERRAIN SCOOTERS

1 SNOW
To push through and glide over the snow, standard wheels are replaced with a smooth sled at the front and a motorised track at the back of snow scooters.

2 WATER
This scooter turns tourists into underwater astronauts with a large observation bubble. It has handlebars, a seat, an oxygen tank and small motors to propel the vehicle through water.

3 MOUNTAIN
Scooters designed for mountain riding usually feature much larger wheels, especially at the front, to add stability to steep slopes and move over obstacles more easily.

4 OFF-ROAD
Off-road scooters have high platforms to avoid rocky obstacles, robust suspension systems and larger wheels with more tread for traction on uneven and unpredictable terrain.

5 SAND
Scooters for travel on soft sand have powerful motors and very wide tyres, providing a larger surface area to spread out the weight and prevent sinking into loose sand.

GETTING AROUND THE SMART WAY

How to navigate the streets on a modern smart mobility scooter

1 TOUCHSCREEN DISPLAY
A touchscreen display on the dashboard allows users to easily access settings, navigation and speed data.

2 VOICE COMMANDS
Voice-recognition technology in modern mobility scooters allows spoken commands to change the speed, turn on the scooter or request directions to a specific location.

3 ANTI-THEFT
Smart mobility scooters come with remote locking and unlocking systems controlled by a connected smartphone.

4 TELEMATICS
As well as being presented on the dashboard, performance data can be accessed through mobile applications. This includes battery level and maintenance information.

5 AUTOMATIC LIGHTS
Some smart scooters have self-illuminating lights that brighten when low light is detected.

6 COLLISION AVOIDANCE
Cameras and infrared sensors can detect obstacles close by and alert the driver if they're in danger of hitting them.

INSIDE A LUXURY HYDROFOIL YACHT

Discover how this all-electric watercraft sails above the surface

WORDS **SCOTT DUTFIELD**


A 3D render of the Icon racing through the water

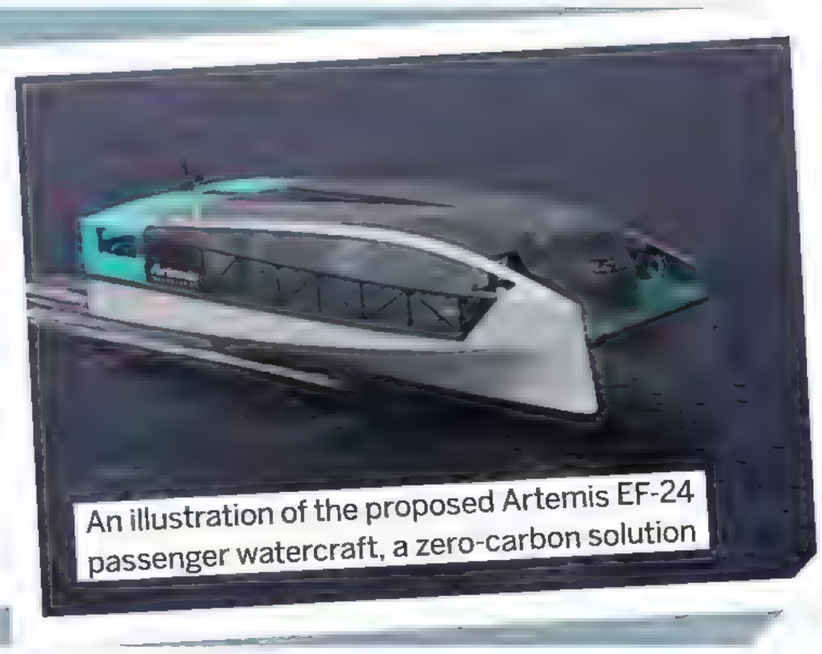
In May 2023, car manufacturer BMW unveiled its new, all-electric foiling watercraft called the Icon, a 13.5-metre-long vessel that relies entirely on battery power. Like other hydrofoil vessels in the ocean, the Icon uses a set of hydrofoil wings and propellers for motion. However, instead of fossil-fuelled motors, propellers are spun by two 100-kilowatt electric motors that are supplied by six batteries beneath the watercraft. Much like the wings of an aircraft, hydrofoils such as the Icon use underwater wings that reduce the amount of drag a vessel experiences, increasing speed and fuel efficiency. They achieve this by utilising Newton's third law of motion, which states that when one object exerts a force on another object, the second object exerts an equal and opposite force on the first. For hydrofoils, this equates to the force pushed down on the water and the water's equal returning force, which keeps it stable while it sails.

The curved shape of a hydrofoil wing is what gives it its hydrodynamic abilities. While moving, water has to travel faster over the longer top side of a hydrofoil wing than the water moving beneath it. As water rapidly passes over the top of the wing, its pressure decreases – a phenomenon known as Bernoulli's principle. The pressure below the wing remains high, which causes the wing to lift upwards. When the force of the lift is greater than the weight of the vessel and the force it applies on the water, the hull of the vessel will rise above the surface and appear to fly above the waves. Thanks to the Icon's hydrofoil wing and hull design, BMW and partner TYDE claim that the energy requirement is reduced by up to 80 per cent compared to other hydrofoil designs. This gives it a range of more than 50 nautical miles, which is around 58 miles.

HYDROFOIL
To extend battery power, hydrofoils have been designed to generate less drag during movement.

FUTURE FERRIES

Private yachts and surfboards are where you'll often find hydrofoil technology. However, there's a growing interest in their use for public transport. As an all-electric alternative to the diesel-guzzling engines of commercial ferries, hydrofoils might become the zero-carbon norm. Hydrofoil ferries aren't a new concept, having been used since the mid-1900s. Several companies around the world are developing all-electric watercraft as a sustainable solution. For example, Artemis Technologies, a Northern Ireland-based manufacturer, is developing several different hydrofoils for public transport, such as the EF-24 passenger craft. Countries around the world are also beginning to turn to future all-electric hydrofoils, including two new hydrofoil Artemis ferries that are set to start a trial service around the Orkney Islands in Scotland in 2025.


An illustration of the proposed Artemis EF-24 passenger watercraft, a zero-carbon solution

The largest passenger hydrofoil in the world weighs 165 tonnes and can carry 250 passengers

1 DIGITAL HELM
From navigation charts to AI-based collision avoidance, all aspects of the vehicle can be accessed through a touchscreen display with voice activation.

2 RECHARGING CABLES
At a standard marina charging station, the Icon's battery system can charge to 50 per cent in just two hours.

BENEATH THE ICON

How this all-electric watercraft stays afloat

3 BATTERIES
High-voltage BMW i3 batteries hold 240 kilowatt hours of power.

4 PROPULSION
Two foil propellers provide a maximum speed of 30 nautical knots, or around 35 miles per hour.

5 CONTROL SYSTEM
Computerised rudders autonomously stabilise the Icon through the vessel's flight-control system.

Inside the Icon are 360-degree rotating chairs and a 32-inch touchscreen control panel

The Icon watercraft at a TYDE charging port

ARTIFICIAL INTELLIGENCE SAILING

The gap between the hull and hydrofoil wings can create instability while a hydrofoil is travelling above the surface of the water. To combat this, Swedish manufacturer Candela has created the C-8 series of hydrofoil watercraft, which use artificial intelligence to correct hydrofoil wing positions in real time. Using an array of sensors around the hull of the C-8, the distance between the vessel and the surface of the water can be continuously monitored. As the distance changes, either as a result of the wind or waves, the AI program informs actuators on the wings, which automatically change their position under the water to keep the vessel as stable as possible.

The Candela C-8 out on the water

FUTURE STEAM POWER

How modern steam trains are ditching coal for cleaner and more efficient engines

DID YOU KNOW? The last passenger steam train in Britain ran between Liverpool and Carlisle in 1968

Encapsulated in billowing clouds, steam trains have been trudging around the world's railway systems for around 200 years. To propel them along their tracks, steam locomotives have used the energy released by combusting fuel, such as coal, to heat a boiler of water. As the water heats and generates steam, the pressure inside the boiler increases. Attached to the boiler is a piston mechanism that feeds on high-pressure steam, causing it to move back and forth and ultimately driving the adjoining train wheel. The steam then finds its way out of the train through a chimney in billowing white-grey clouds of exhaust.

Using an external combustion engine, traditional steam trains ran the risk of rogue embers igniting other fuel on the train or damaging the tracks below. To mitigate this risk, the first fireless locomotives were introduced to the world in 1882. Like other steam engines, superheated water was the source of their propulsion, but the water was loaded into the locomotives, preheated and pressurised. This meant that the locomotives could only run for as long as the water stayed hot, or until the water ran out.

Did you know?
America's first steam train lost a race with a horse

During their heyday, steam locomotives were adapted to carry tonnes of freight and move passengers up mountainsides. However, by the 1930s coal-fuelled steam trains were in decline, with diesel and electric-powered trains leading the charge as the modern way to travel. Steam trains haven't disappeared completely, though, remaining in use around the world for both recreational and practical purposes. While the mechanics of steam locomotives remain similar today as they did during the early 1900s, there have been some upgrades to the way they consume fuel. For example, some locomotives have adopted a Gas Producer Combustion System (GPCS) to enhance fuel efficiency. This system reduces the amount of airflow into the firebox and redirects some of the steam from the engine to increase the efficiency of the coal's combustion.

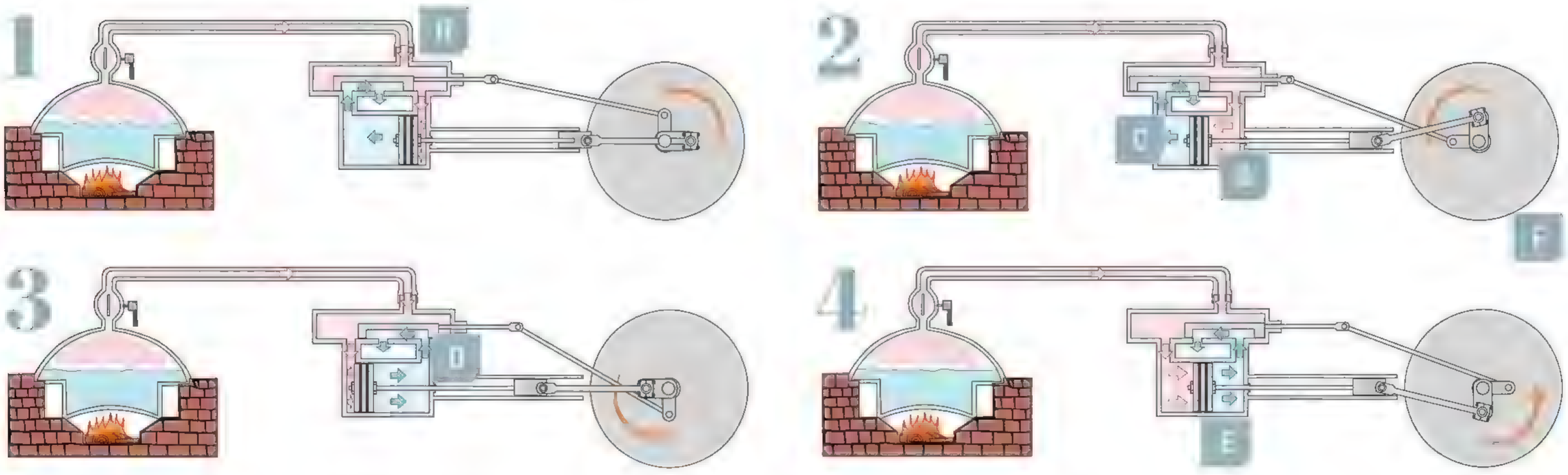
In place of the coal piles of traditional steam trains, many modern locomotives are adopting different types of fuel, such as oil or biofuels. German train manufacturer Dampflokomotiv- und Maschinenfabrik (DLM) has developed steam-powered locomotives that have replaced coal with a 'light oil firing system' to reduce greenhouse gas emissions and provide the driver with better control of the train. DLM recently completed the conversion of a traditional 99 787 steam locomotive from coal to this light oil firing system.

Researchers are also finding new and interesting ways to keep people's passion for the steam locomotive alive, without the environmental cost of burning coal. At the University of Minnesota's Natural Resource Research Institute (NRRI), scientists have transformed a plant-based material into a carbon-neutral biocoal, known as torrefied biomass. The process of torrefaction requires plant matter, such as wood, to be heated up to around 300 degrees Celsius in the absence of oxygen. The resulting blocks of biocoals release far less carbon dioxide than traditional coal but still burn at a 96 per cent thermal efficiency.

"Many modern locomotives are adopting different types of fuel"

GAINING TRACTION

The physics that move steam trains along the tracks



A STEAM IN
Superheated steam from the boiler enters the steam engine's cylinder behind the piston.

B MOVING THE PISTON
As more high-pressure superheated steam enters the cylinder, the piston is driven forward.

C REMOVING STEAM
Steam from the previous stroke is forced out of the valve and exhausted out of the train's cylinder.

D CHANGING DIRECTION
An arm moves as the wheel turns to open and close the exhaust valve, ensuring that spent steam is removed and superheated gas continually moves the piston.

E TURNING THE WHEEL
To complete a full turn of the train's wheel, the piston is forced backwards by the steam and again exhausts the steam from the previous stroke.

F CONNECTING ROD
The piston is directly connected to a connecting rod that turns the wheel as it is pumped back and forth.

An oil-fired steam locomotive driving up the Brienzer Rothorn mountain in Switzerland

THE SCIENCE OF STEAM

How modern steam trains turn boiling water into propulsion

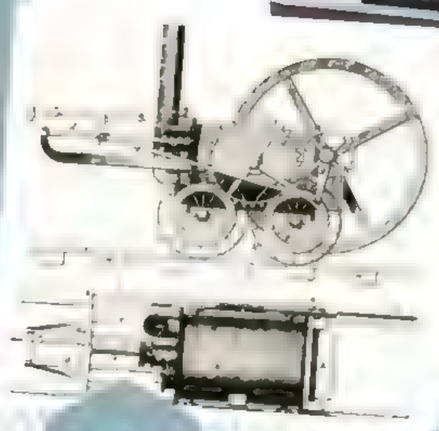
1 FUEL
A light crude oil reservoir feeds fuel into the firebox to be combusted.

2 FIREBOX
Oil is funnelled into the firebox and ignited to generate enough heat to boil the surrounding water-filled boiler.

HEILMANN'S STEAM-ELECTRIC LOCOMOTIVE

With an ambition to combine steam propulsion with electrical power, French train pioneer Jean-Jacques Heilmann patented the first locomotive that used a steam engine to generate electricity in 1890. The original Heilmann locomotive, a 16.3-metre-long train, was driven by a two-cylinder steam engine that turned a 400-kilowatt generator for electrical propulsion. A completed locomotive was showcased in 1893 on a test run in Paris. The following year, in a test run carrying 250 guests on the railway network in Compiègne, it reached a top speed of around 67 miles per hour. However, due to the complexity and expense of building trains that used steam and electricity, Heilmann's locomotives weren't further developed or constructed.

An illustration of one of Heilmann's experimental steam-electric locomotives



STEAM TRAIN EVOLUTION

1804
The first-ever steam locomotive, built by British inventor Richard Trevithick, ran along a track in Wales.

1814
Engineer George Stephenson built the 'travelling engine' – the first practical steam locomotive to ferry coal.

1825
American inventor John Stevens built the first steam locomotive with a multi-tube boiler engine.

1829
Robert Stephenson showcased his steam locomotive called 'the Rocket', which could reach speeds in excess of 30 miles per hour.

The world's largest steam locomotive is 40.5 metres long and weighs over 544 tonnes

3 HEATING WATER
Hot air, produced by the combustion of oil, flows through pipes surrounded by water.

4 CREATING STEAM
Water housed in a tank is heated to more than 205 degrees Celsius to generate steam.

5 SUPERHEATED STEAM
Steam passes through a series of pipes close to the firebox, reaching around 420 degrees Celsius.

8 CHIMNEY STEAM
The steam exhaust and excess heat are vented and released into the atmosphere via the chimney.

6 ENTER THE ENGINE
The superheated steam enters the train's piston engine to drive the crankshaft.

9 STEAM BRAKES
Steam produced in the boiler is also used in the train's braking system.

7 TURNING THE WHEELS
The driving rod connected to the engine drives the train's wheels along the track.

1830

The first American passenger locomotive, called 'Tom Thumb', was constructed by Peter Cooper.

1831

The John Bull passenger steam train was the first locomotive fitted with headlights and a 'cowcatcher' to deflect obstacles on the track.

1923

The Flying Scotsman was the first steam locomotive to reach 100 miles per hour.

WHAT ARE CAT'S EYES?

These glowing road safety devices have steered drivers in the right direction for decades

WORDS **AILSA HARVEY**

When travelling along roads at night, drivers rely on well-lit paths and signage to direct them safely along dark routes. Road signs have lights to illuminate their lettering, while between lanes, long strings of small studs inform the positioning of each vehicle. Just as any cat caught in the headlights reveals two piercingly bright eyes, these road studs shine brighter the closer you drive towards them, reflecting the light from car headlights back to the vehicle.

Cat's eyes were first produced by English inventor Percy Shaw in 1934. When Shaw was driving along a particularly dangerous section of road on a foggy night a year prior, he was unable to see where the road ended and the steep hills began. He usually used the reflection of his headlights off the tram tracks in the road to guide him, but on this misty night he realised the need for clearer road markings. None of the roadside objects reflected much light back to him, other than the eyes of a passing cat. This striking return of light led Shaw to design an unpowered device that could achieve this same level of brightness along all stretches of a road and make driving after dark much safer.

Today, cat's eyes are a staple of road design, preventing many accidents as a result of poor visibility. They are widely used in countries around the world and don't depend on electricity to work – just the light already produced by your vehicle. There are around 500 million cat's eyes lining roads in the UK alone.

Though the simple-yet-effective reflective design has stood the test of time, a modern spin on cat's eyes sees the technology incorporating small solar panels to emit light constantly through each night. This allows them to shine brightly at a distance as well as at close range so drivers can view twists and turns more clearly from afar.

Orange-lit glass domes can be seen at the centre of the white rubber housing and aluminium casing

SELF-CLEANING INSTALLATION

For the best reflection and clear road marking, cat's eyes need to be clean in order to reflect a car's headlights. The central glass reflecting component of a cat's eye is first placed into a rubber housing. When positioned in the housing, cat's eyes are slightly elevated from the road surface level. This makes them stand out and enables light from headlights to better reach their surface. The rubber housing is placed into a hard aluminium casing before it's placed onto the road. Much of the sturdy metal shield is fitted so that it doesn't move, but the section with the rubber housing moves up and down slightly under the weight of a vehicle's tyres. By dipping slightly below the road's surface upon impact, the tyres are less likely to be damaged. Meanwhile, the moving parts rub against the non-moving parts slightly, wiping away any debris covering the surface of the cat's eye stud to keep it clean.

Cat's eye colours show lane boundaries and motorway exit lanes

HOW THE EYES PRODUCE THEIR GLARE

Since the first cat's eyes were installed in the 1930s, the general structure and function of the technology has remained largely consistent. In cat's eyes that don't have batteries, the road studs have a central glass dome called a retroreflector. Retroreflectors are essential for the purpose of driving at night, as they reflect light back in the direction that it was emitted from. This means that when a car's headlights project light onto the road in front of them, the light bounces back from the cat's eyes to the driver, and the driver clearly sees these bright guidance markings.

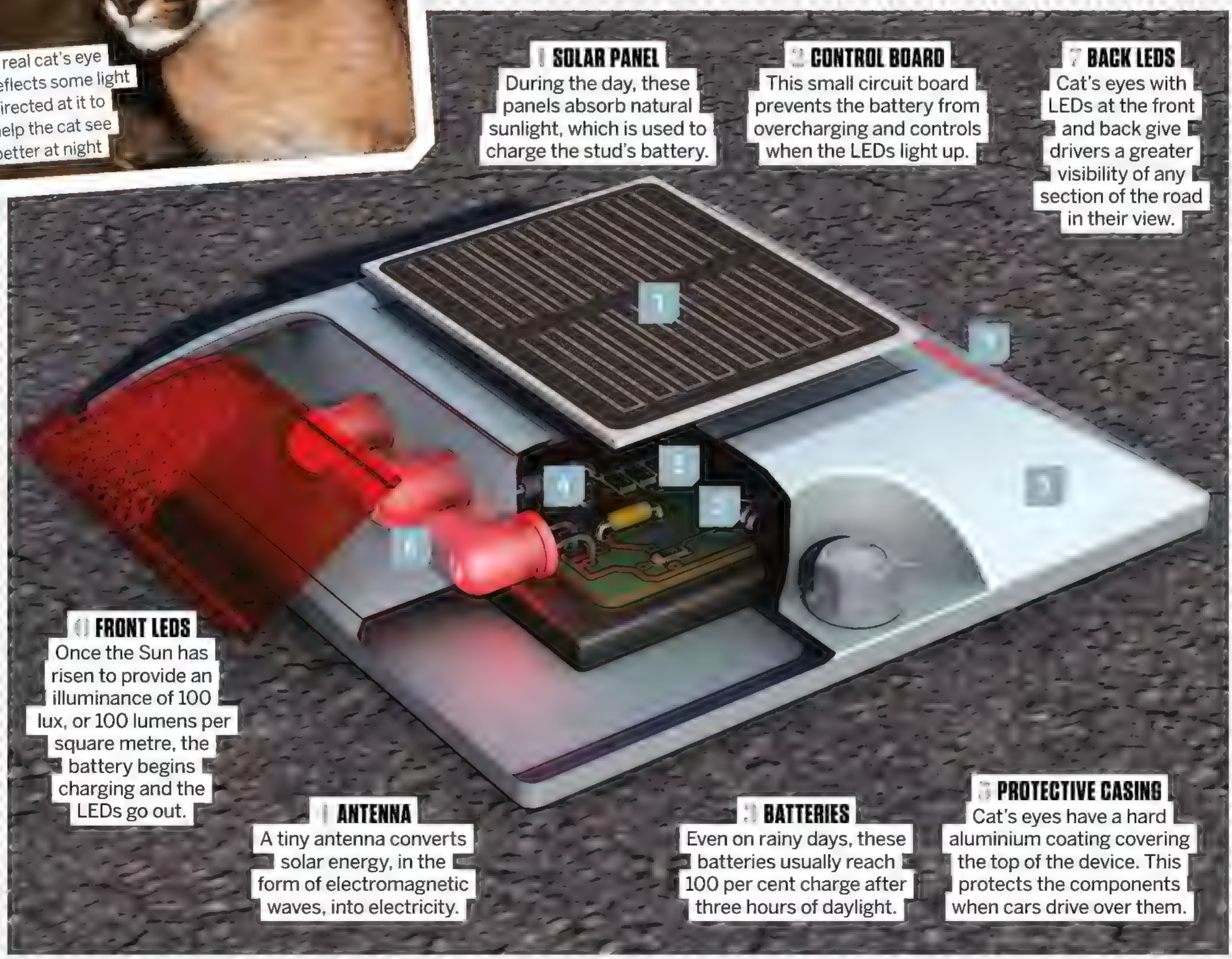
When the light first makes contact with the cat's eye, it hits a glass dome-shaped lens. This lens refracts (bends) light towards the back of the structure. A mirror at the back of the eye reflects light back to the curved glass lens, which refracts light again at the same angle. As a result, the light leaves the glass dome in a parallel line to how it arrived. Without this accurate redirection, there wouldn't be clear, visible lanes.

When removed from its protective casing, a traditional cat's eye is a small glass dome

A real cat's eye reflects some light directed at it to help the cat see better at night

SOLAR-POWERED STUDS

This type of cat's eye produces light using the Sun's energy



1 SOLAR PANEL
During the day, these panels absorb natural sunlight, which is used to charge the stud's battery.

2 CONTROL BOARD
This small circuit board prevents the battery from overcharging and controls when the LEDs light up.

7 BACK LEDS
Cat's eyes with LEDs at the front and back give drivers a greater visibility of any section of the road in their view.

4 FRONT LEDS
Once the Sun has risen to provide an illuminance of 100 lux, or 100 lumens per square metre, the battery begins charging and the LEDs go out.

6 ANTENNA
A tiny antenna converts solar energy, in the form of electromagnetic waves, into electricity.

3 BATTERIES
Even on rainy days, these batteries usually reach 100 per cent charge after three hours of daylight.

5 PROTECTIVE CASING
Cat's eyes have a hard aluminium coating covering the top of the device. This protects the components when cars drive over them.

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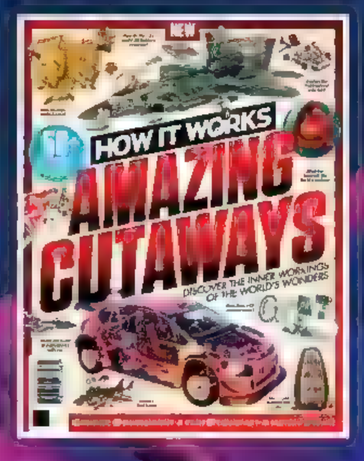

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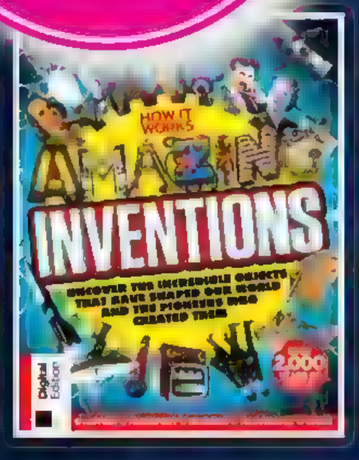

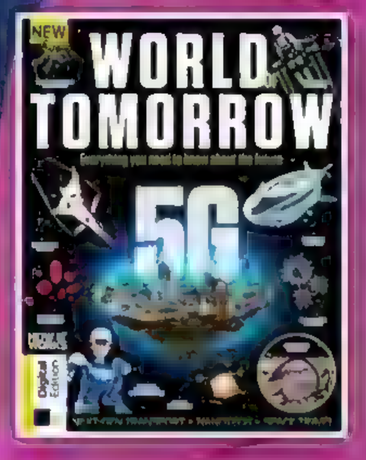

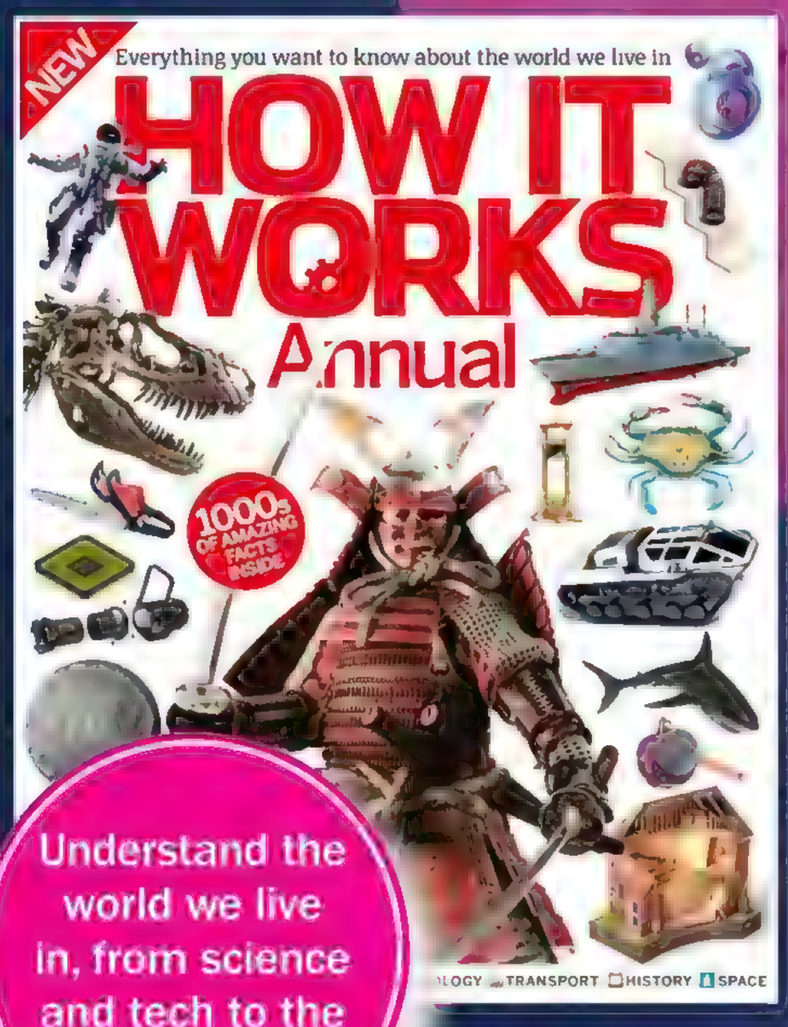

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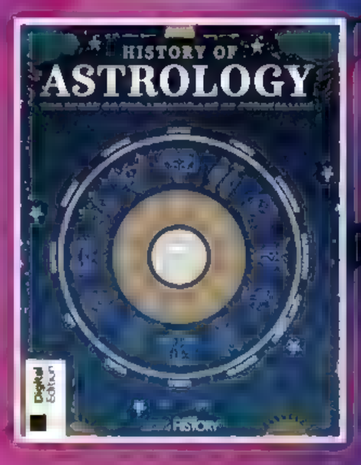

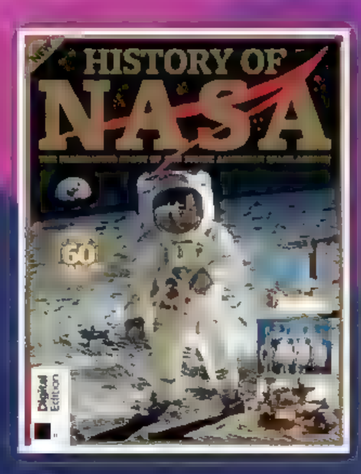

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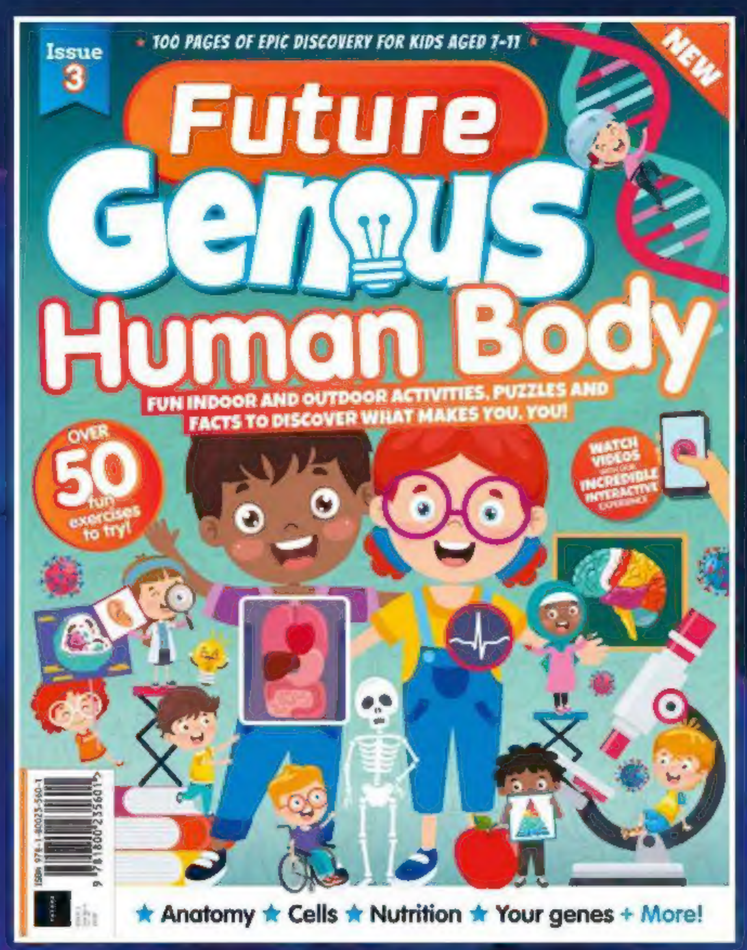

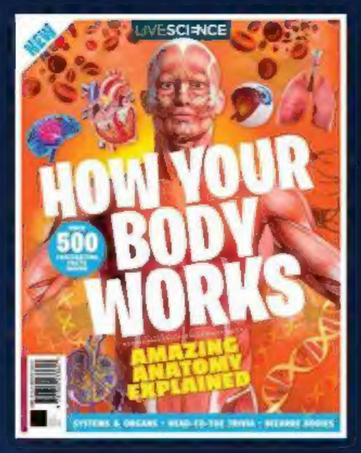

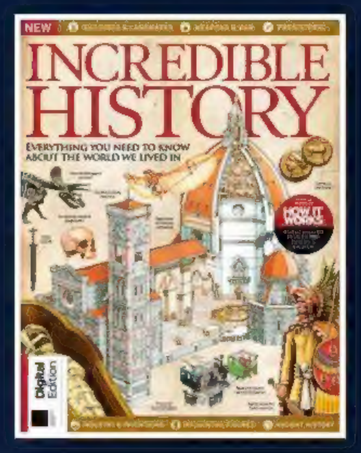

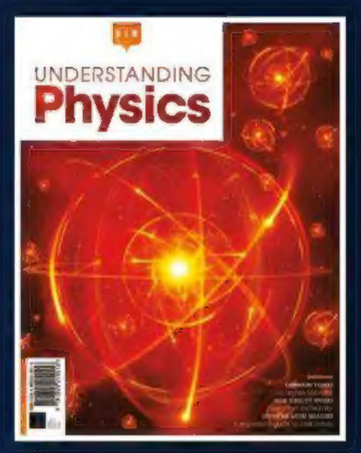

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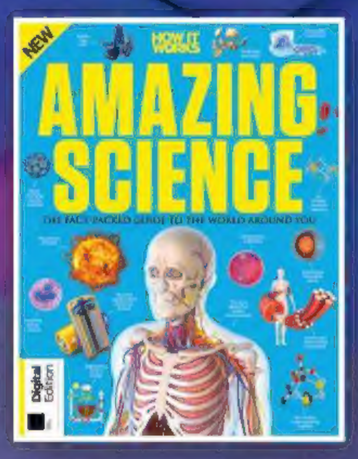

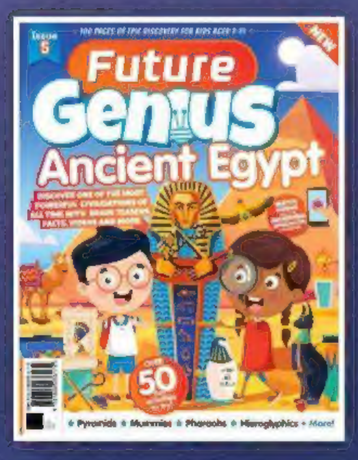

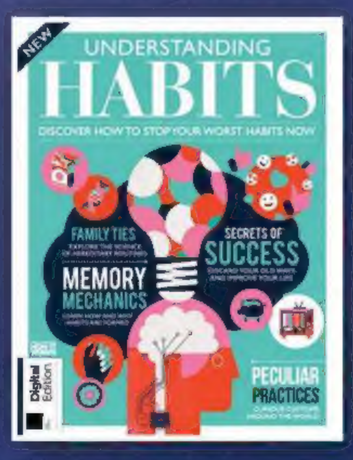

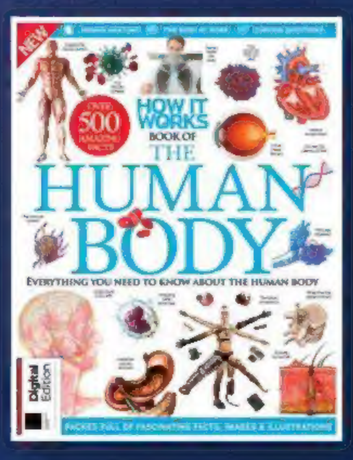

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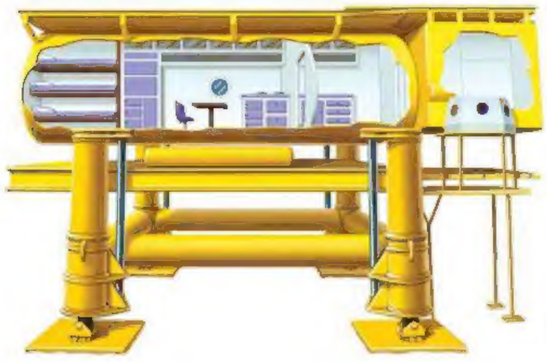

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